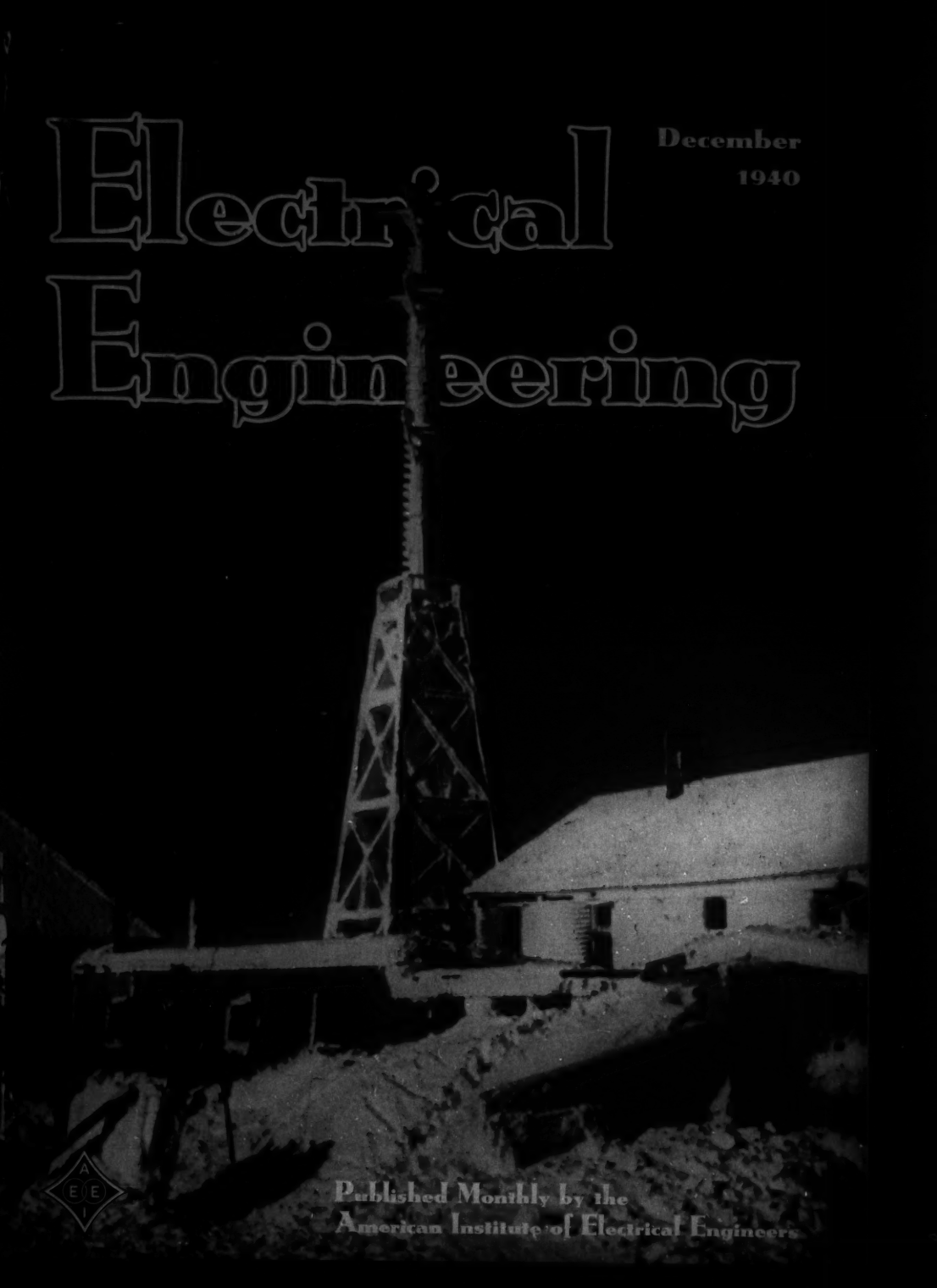
Electrical Engineering

December
1940



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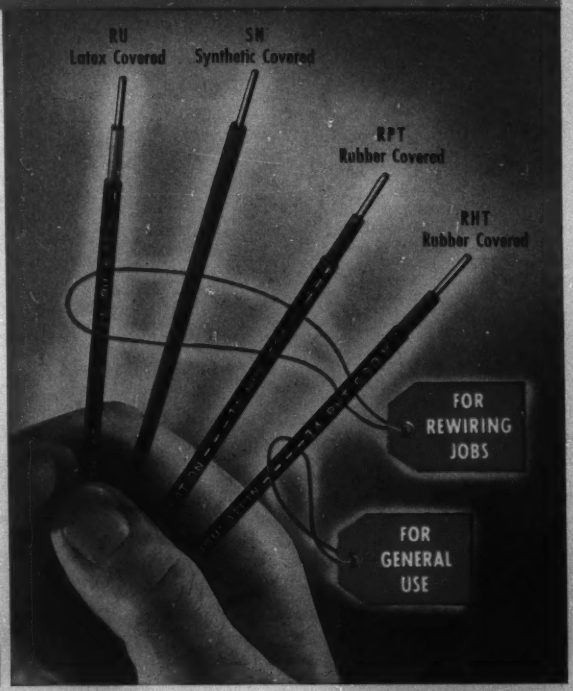

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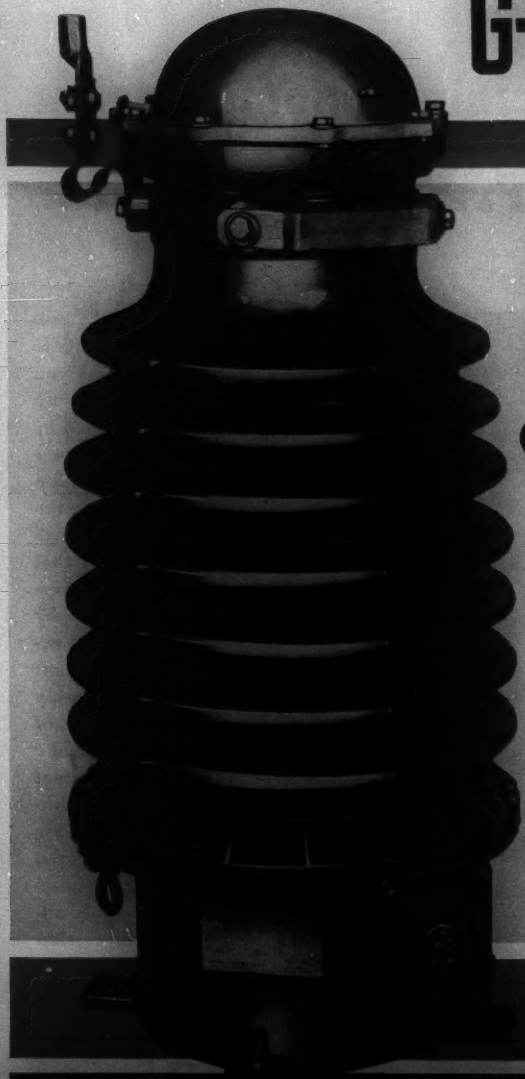

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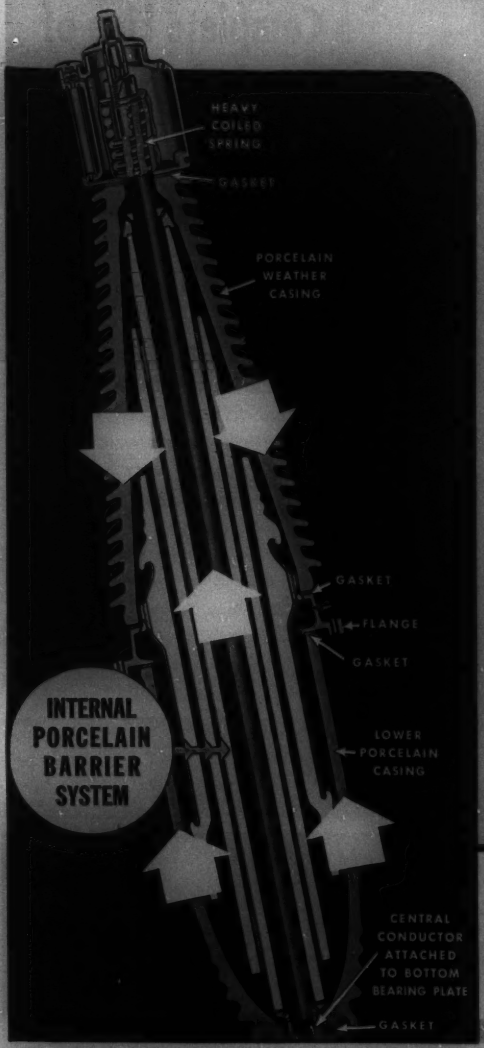

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High Lights • •

"Blind" Landing. For some years radio aids to air navigation have made it possible for airplane pilots to fly when weather conditions are such that they cannot see the ground, but flights still must be cancelled when conditions at the destination are such that the pilots cannot see to land. Most promising of the various attempted solutions of this number 1 problem of aviation are ultrahigh-frequency radio systems, in which directive beams radiated from transmitters on the ground are received on the air planes and translated into appropriate instrument indications, thereby furnishing pilots with information that will enable them to land regardless of weather conditions. One such system has been developed to the point where it is being installed at ten important airports throughout the United States for an extended period of instrument or "blind" landing tests (*pages 495–502*).

Electronic Tubes. During the past decade the variety of types and the applications of electronic tubes increased greatly. A review of progress in the use of tubes in this period divides into two parts: the field of communication, and other uses. In communication, radio has advanced steadily to higher frequencies, broad-band carrier systems have been introduced in telephony, and television and frequency-modulation broadcasting have appeared—progress in which electronic devices have had an important role (*Transactions pages 643–9*). Nearly the whole period during which tubes have been applied in other than the field of communication is included in the past ten years. Here tubes are in competition with other devices, and must make their own way on the basis of lower cost (*Transactions pages 650–4*).

Frequency Modulation. Because of its great advantages over the present amplitude-modulation system of radio communication, the frequency-modulation system, under development for the past several years, now bids fair to become the dominant system in radiobroadcasting. In this issue, Major Edwin H. Armstrong, its inventor, traces the history of this new method of communication, outlines its advantages, indicates its present status, and predicts that "within the next five years the existing broadcast system will be largely superseded" (*pages 435–93*).

Impregnated-Paper Insulation. The requirement of mechanical flexibility in cable is at the root of the present method of applying paper insulation in spiral tape form in successive layers, but it is not always possible to retain maximum flexibility and maximum dielectric strength and stability. Paper selection should ensure the optimum combination for a particular cable; one factor is the thickness of the paper. Accelerated voltage-time tests have been made with this as the variable (*Transactions pages 660–3*).

National Defense. Among recent developments in national defense preparations of particular significance to the engineering profession are the announcement of a $9,000,000 program of Government-financed defense-personnel trainining in the engineering colleges (*pages 521–2*) and the National Resources Board's recent request for co-operation by engineering and other societies in preparing a roster of scientific and specialized personnel in the Uuited States (*page 521*).

Nomography. Many computations in electrical-engineering work, particularly those involving the repeated substitutions of several variables in the same equation, can be expedited by the use of nomographic charts. In an article in this issue, the basic theory underlying these charts is outlined, and the application of the method illustrated by several examples involving familiar equations (*pages 505–08*).

Current Transformers. Most of the information concerning current transformers has been derived from tests on models. A new method of calculating the accuracy of current transformers, making use in so far as possible of the well-established power-transformer formulas, avoids the making and testing of models and enables the design to be made for a specific application (*Transactions pages 663–8*).

Reference Values. Engineering measurements frequently require that readings taken with the prevailing conditions of temperature, humidity, and barometric pressure be referred to standard reference values. At best all reference values must be a compromise for broader variations encountered by equipment in service, and therefore their number should be minimized (*Transactions pages 669–75*).

New Code. The 1940 National Electrical Code, recently approved as an American Standard, embodies significant changes as compared with the last previous edition (1937). In an especially prepared statement, the chairman of the committee responsible for compiling the Code discusses some of these changes (*pages 503–04*).

Potential Devices. Several limitations govern the rating and application of capacitance potential devices. To supply the need for co-ordinated practice, a paper outlining the basis of rating for the purpose of formulating standards has been prepared at the request of the AIEE relay subcommittee (*Transactions pages 676–80*).

Radio-Frequency Measurements. Although the same basic principles are used in measurements at power and radio frequencies, different techniques are required because of changes in circuit elements with frequency. The art is growing rapidly as new instruments become available (*Transactions pages 654–9*).

Detecting Ionization. A cathode-ray oscilloscope used in connection with an appropriate air-core reactor has been found to detect ionization in electrical apparatus at or below the minimum voltage at which radio interference may be noted by the "radio noise influence voltage" method (*Transactions pages 680–2*).

ECPD Annual Meeting. A complete list of engineering-school curricula accredited by the Engineers' Council for Professional Development as of October 24, 1940 appears in this issue (*pages 522–3*), in addition to a report of the annual meeting held that date (*pages 524–5*).

Winter Convention. Inspection trips are being emphasized by the 1941 winter convention committee in its plans for the convention at Philadelphia, Pa., January 27–31. Trips planned at present are outlined in this issue (*pages 510–12*).

Greetings From The President. A Christmas message to Institute members from President Royal W. Sorensen presents impressions gained in his presidential travels, and observations on Institute membership and on national defense (*pages 509–10*).

AIEE Budget. The report of Institute income and expenditures for the year ending September 30, 1940, and the budget for the year 1940–41, are presented in tabular form, accompanied by a report from the finance committee (*page 513*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: an article on practical applications of research by E. S. Lee (F'30); an article discussing sun-spot disturbances of terrestrial magnetism by W. F. Davidson (F'26); a paper describing an investigation of the starting requirements of a 660-horsepower locomotive Diesel engine by J. C. Davidson (A'07) and R. Lamborn (A'26); a paper on the application of electricity for the auxiliaries of railroad trains by J. E. Gardner (M'37); a paper describing some characteristics and applications of negative-glow lamps by H. M. Ferree (A'40); a paper on vario-losser circuits by W. R. Bennett (A'40) and S. Doba; a paper on power-factor testing of transformer insulation by J. B. Hodtum (M'26); a paper describing an improved a-c pilot-wire relay by J. H. Neher (M'38) and A. J. McConnell (A'36); a paper on superposition methods for calculating effects of additions to power systems by V. G. Rettig (A'32); a paper on possibilities and methods of extending a carrier-current relay channel to other uses by R. M. Smith (A'35) and S. L. Goldsborough (A'24); and a paper describing a push-button-tuned 50-kw broadcast transmitter by R. J. Rockwell and H. Lepple.

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Copyright 1940 by the American Institute of Electrical Engineers. Printed in the United States of America.
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Evolution of Frequency Modulation

EDWIN H. ARMSTRONG

Embracing the substance of lectures presented before many AIEE Sections and other groups, and particularly of an address delivered at the 1940 AIEE Pacific Coast convention, this article by the inventor indicates briefly how the frequency-modulation system of radio communication differs from the present amplitude-modulation system, traces the history of this new system, points out its advantages over the amplitude-modulation system, and indicates the extent of its probable applications in the future.

SOME 60 years ago the electric-power industry began the development of a system of distribution which all are now agreed was not the right system. I am referring of course to the low-voltage d-c system. The inevitableness of its replacement by the high-voltage a-c system is now obvious to everyone, although the literature of the transition stage reflects a period of violently conflicting opinion.

A part of the radio industry, in fact by far the largest part, is about to pass through a similar transition. It has become obvious that the present system of broadcasting is not the best, and that its faults are readily curable by the introduction of new technical methods. The characteristics of this new system are such as to provide practically perfect solutions of most of the troubles of the present structure.

These faults are, specifically referring to the broadcast industry: the interruption or marring of the transmission by natural (lightning) or man-made static; the inability either to transmit the full musical range because of a lack of available channel space in the frequency spectrum, or to transmit that part which can be transmitted with full fidelity; the drastic mutual curtailment of the service ranges of two stations on the same wave lengths, even though separated hundreds of miles; and the distortion of the reproduction at certain points in the transmission paths by a phenomenon of propagation known as selective side-band fading. These difficulties and disabilities of present-day broadcasting are about to disappear with the introduction of a new system which has become popularly known as "frequency modulation," although much more is involved than a method of modulation per se.[1] Some 15 broadcast stations employing this system are now in operation and some hundreds are projected.

The problems solved are not merely technical ones. Since the system is primarily adapted for use in the ultra-high-frequency part of the spectrum, so much new frequency space becomes practically available that it has become possible to allot channel facilities to every town in the country. The factor that determines whether a community may have a station to serve its local needs is no longer the availability of channel space, but the economic ability of the community to support it. The development of local broadcast service within these smaller communities will play an increasingly important part in the broadcasting of the future.

EDWIN H. ARMSTRONG is professor of electrical engineering, Columbia University, New York, N. Y. Major Armstrong ranks as one of the outstanding radio inventors of all time, having previously contributed the inventions of the regenerative circuit, the superheterodyne circuit, and the superregenerative circuit.

1. For numbered references see list at end of article.

MODULATION

Modulation in radio signaling is the process of changing some characteristic of the radio wave in accordance with the intelligence to be transmitted. The earliest form of modulation was the interruption or the breaking up of the radiated energy into the long and short pulses of the Morse code by means of a telegraph key, although in those days the term "modulation" was not used. Subsequently, with the introduction of continuous-wave generators, as distinguished from the "damped" wave or spark type of transmitter, it became possible to superimpose the characteristics of the voice or music on the radio wave. The method employed followed closely upon an early form of wire telephone transmission in which the strength of a current flowing through the line was varied in accordance with the tones of the voice, the number of times per second the direct current was "modulated" above and below its normal value corresponding to the frequency of the tone to be transmitted (considering, for example, a single tone), and the magnitude of the change corresponding to its loudness. In the earliest form of radio telephony the strength of the antenna current at the transmitter (in this case alternating several hundred thousand or more times per second) was varied in amplitude by a microphone connected in the path of the current. At the receiver, in the circuits of which currents corresponding in form to those transmitted were flowing, the variations in the amplitude of the high-frequency current were converted by means of a rectifying detector into currents corresponding in frequency and amplitude to those which the microphone would have created were it "modulating" a direct current. These currents may be observed in an ordinary telephone receiver.

The difficulties of handling large antenna currents by either a single microphone or a group of microphones led to various proposals for another form of modulation known then as "wave length" modulation. In this method, the amplitude of the antenna current remained unchanged, but the wave length or frequency was periodically increased above and decreased below a certain resting value,

the number of times per second the frequency was swung about the midpoint being determined by the frequency of the tone to be transmitted, and the extent of the change above and below (or the "deviation" from) the mid-frequency point being proportional to the strength or loudness of the tone. It was proposed to effect this kind of modulation at the transmitter by changing the inductance or capacitance of the circuit controlling the frequency of the oscillation generator by means of some electrostatic or electromagnetic microphone. Since no change in amplitude of the radio wave was produced, the transmission could not be received by the ordinary means. It was proposed to effect reception of waves with this type of modulation by causing the changes in frequency in the received wave to produce changes in amplitude by the use of mistuned selective circuits so that as the incoming variable-frequency current came closer into or receded farther from the resonant frequency of the selective circuit, the amplitude of the currents therein would be correspondingly varied and so could be detected by the usual rectifying means. No practical success attended these proposals, and the literature attests the fact that the early art struggled on with amplitude modulation. About 1914 the advent of the vacuum-tube modulator so completely solved the problems of amplitude modulation that for almost a decade frequency modulation was forgotten.

In 1922 the possibility of its use as a means of reducing the band width required to transmit a given range of frequencies was examined mathematically by Carson[2] who dispelled the illusion that a saving in spectrum space could be obtained over that required by the amplitude-modulation method. Carson proved that at least the same and usually a greater space was required by the frequency-modulation method. Other conclusions unfavorable to the frequency-modulation method were reached. The principal conclusions were subsequently confirmed by other mathematical treatments.

"STATIC"

The major problem of radio signaling for about 30 years has been the interference caused by various forms of natural and man-made electrical disturbances. While radio communication has always been subject to disturbances during lightning storms, the introduction of the vacuum-tube amplifier and the regenerative circuit in 1912 made the problem an ever-present one, as almost any signal could be received, however weak, provided it could be separated from the disturbing impulses which likewise, however weak, were always present. With the coming of broadcasting, which brought the location of the receiving system into areas where high levels of "man-made static" existed, and with the improvements in the sensitivity of the receivers themselves, which finally reached a point where fluctuations in the flow of electrons in the early stages of the amplifier circuits became capable of producing disturbances, the noise problem became the all-pervading one in the art.

Realization of the nature of the problem by those engaged in its study developed slowly. Following the introduction of the new methods of reception in 1912, a vast amount of work was done on the theory that the disturbing waves of natural origin were different in kind from those used in signaling and that circuit arrangements could be devised to differentiate between them. The patent literature of the art of this time furnishes an illuminating illustration of the amount of ingenuity that can be exercised along lines of unsound theory.

It was finally realized that the nature of these disturbances is that of a spectrum which contains all component frequencies, some of which always coincide with those being used in any particular case for transmitting the signal. Carson placed the matter on a quantitative basis in 1925.[3] Subsequently it was shown that many of the man-made disturbances are similar in make-up to those of natural origin and finally that the constitution of the disturbances originating in the irregularities of the motion of the electrons in tubes and circuits is likewise that of a spectrum. The amount of energy absorbed by any electrical system subjected to disturbances of this character depends on the width of the frequency band passed by the selective circuits of the system. Consequently it became a principle of design to make the admittance band of a receiver just sufficiently wide to pass the frequency components necessary to convey the signal, and no wider. The presence of the residual noise came to be accepted as a necessary evil.

Subsequent to the publication of the 1925 Carson article,[3] it occurred to the writer that the use of a system of signaling in which only changes in frequency of a transmitted wave could be observed in a receiver (which was made nonresponsive to amplitude changes) might furnish a means of distinguishing between the desired and undesired currents. An experimental investigation under actual working conditions using a receiver provided with a device for limiting out amplitude changes led to the conclusion that the currents set up in the receiving system by the waves of natural origin were modulated in frequency as well as in amplitude and that no major improvement could be thus effected. These observations were made with the frequency band width of the transmission and reception kept to the narrowest possible limits.

During the course of this work, however, an observation was made which seemed to indicate that the changes in frequency of the disturbing currents were limited in extent. This suggested the idea that if the transmitted wave were modulated widely in frequency and if the receiver were made nonresponsive to amplitude changes, feebly responsive to small changes in frequency, and fully responsive only to the wide frequency changes of the signal, a means of differentiating between desired and undesired currents might be found. With this relatively crude conception of a possible solution the necessary experimental work was undertaken. It resulted in the discovery of a new principle in noise reduction, the application of which furnishes an interesting conflict with the principle that had been the guide to the art for years. In accordance with this principle it was found that in a frequency-modulation system which is not responsive to amplitude changes within its working limits (noise not greater than one-half the signaling current), the wider the band used in trans-

Figure 1. Frequency-modulator setup in shielded room used in early experimental work

mitting the signal the better the signal-to-noise ratio. The power gain of the signal-to-noise ratio increases as the square of the frequency band width used, and gains of a thousandfold or more can be realized in practice. Now the actual mechanism of the process by which the gain is achieved is much more involved than the foregoing explanation would indicate. It may be treated in various ways, but it is beyond the scope of this article to examine it in detail. A full explanation may be found in the writer's paper[1] presented before the Institute of Radio Engineers in 1935. The recent AIEE paper by Everitt likewise contains a detailed explanation.[4] Further reference to this process will be made hereinafter.

TRANSMITTING AND RECEIVING METHODS

In order to carry out the experimental investigation just mentioned, it was necessary to produce both transmitting and receiving equipment. An extensive experience with the known methods of obtaining frequency-modulated signals and their shortcomings led to the development of a new method which gave a complete solution to the problem of producing large frequency changes of a carrier at the relatively high frequencies where of necessity the new system had to operate in order to find available channel space. This method consists in employing the modulating current to shift the phase of a current derived from a source of fixed phase and frequency (usually about 200 kilocycles) by an amount directly proportional to the amplitude of the modulating current and inversely proportional to its frequency. The resulting phase shift is then multiplied several thousandfold by means of a series of frequency multipliers. By keeping the initial phase shift below 30 degrees substantial linearity can be obtained. Some three to five thousandfold multiplication is required in order to give an over-all frequency swing of 150,000 cycles at a transmitting frequency of 40 megacycles. Since it is desirable to perform the initial phase-shifting operation at a frequency of the order of 200,000 cycles the multiplication is carried out in two stages. The first stage usually converts its 200-kilocycle input to 12.8 megacycles; this frequency then is heterodyned with a frequency differing from 12.8 megacycles by a submultiple of the frequency which it is desired to transmit. Where the transmitter frequency is of the order of 40 megacycles the submultiple frequency may be of the order of 600 to 900 kilocycles. This current is then passed through a second series of multipliers until the desired output frequency is obtained, where its power is increased to any required amount by a series of amplifiers.

The receiving equipment follows amplitude-modulation

Figure 2. Early experimental frequency-modulation receiving equipment

practice along certain general lines. The superheterodyne method of reception is employed with two additional pieces of apparatus. The first detector or converter of the superheterodyne and the intermediate-frequency amplifier follow standard practice with the exception that the intermediate amplifier has a much broader frequency-band width and greater amplification than in the ordinary amplitude-modulation system. One of the two additional pieces of apparatus is a device for removing changes in amplitude from the received wave so that only pure frequency-modulated current is passed on for detection. This device is generally an overloaded vacuum-tube amplifier in which the screen and plate voltages are reduced to cause the tube to give a limited output; hence it is commonly referred to as a "limiter". It is connected to the output of the intermediate-frequency amplifier and usually requires several volts to be applied to its grid for effective operation. The second device is an arrangement of circuits in which the transmission characteristics with respect to frequency vary linearly over the range of the intermediate frequency through which the signal sweeps. It is placed after the limiter and before the detector, and its function is to convert the frequency changes linearly into amplitude changes. The name "discriminator" is commonly applied to this kind of device. Usually a differential or balanced type of detector is employed.

FIELD TESTS

The many years of research required to test out the principle were carried out in the Marcellus Hartley Research Laboratory at Columbia University, New York, N. Y. Since both ends of the system of necessity had to be under simultaneous observation, the transmitting and receiving equipment were located in adjoining rooms, the distance over which signals were transmitted being some 50 feet. During the winter of 1933–34 the system was demonstrated in the laboratory to the executives and engineers of the Radio Corporation of America for several months. Laboratory experiments in the "static eliminator" field being subject to quite justifiable suspicion, the transmitting equipment was removed from Columbia in the spring of 1934 and installed at the National Broadcasting Company's station located at the top of the Empire State Building in New York. This station had a 2-kw 44-megacycle transmitter which was originally intended for television, but which was not in use at the time. It was modified so as to transmit the wide-band frequency-modulation signals. Two modulators of the type heretofore described are shown in figure 1. They were located in a shielded room adjacent to the power-amplifier equipment and hence could be operated in the open as shown. The receiving system was located at Westhampton Beach, Long Island, about 70 miles from New York City. Figure 2 shows the receiving equipment as installed there in June 1934. The excellence of the results obtained in the initial tests surpassed all expectations, perfectly quiet reception being secured through the heaviest thunderstorms when all the standard broadcast services had been rendered utterly useless. As Westhampton Beach was obviously too favorable a site, the receiver was removed in July to Haddonfield, N. J., near Camden, a distance of about 85 miles from New York, where successful operation likewise was obtained.

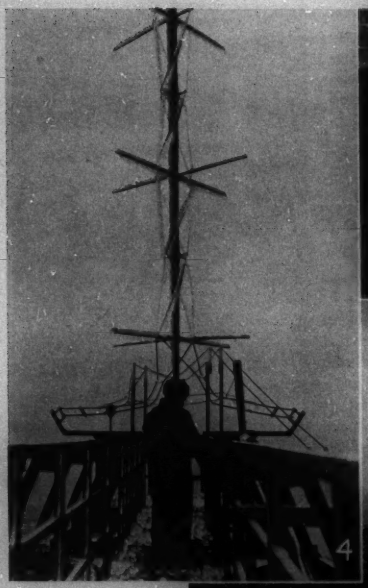
In all these tests much greater improvement in the signal-to-noise ratio was obtained than the thousandfold gain heretofore referred to, as in addition to the improvement due to the use of frequency modulation much less static is encountered on the ultrahigh frequencies than in the standard broadcast band. A pleasant surprise was the establishment of the fact that ultrahigh-frequency transmission, contrary to the accepted belief, did not stop abruptly at the horizon (about 45 miles for the Empire State tower) but could be successfully received up to at least three horizons. The complete absence of all the effects of selective side-band fading from which the standard band suffers was proved, and all the fears of limited coverage were set at rest.

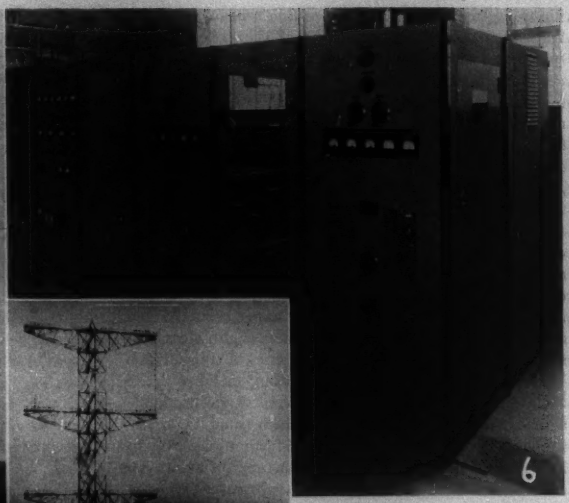
Up to this point the development of the system had proceeded in a normal way, similarly to the pattern followed in the introduction of many other inventions into American radio. However, numberless objections began to be raised regarding the utility of the new system; and although for over a year and a half tests were conducted under all conceivable conditions and repeated demonstrations and comparisons with the existing broadcast system carried out, the Radio Corporation declined to put the invention into public use. The Empire State transmitter was withdrawn from further frequency-modulation tests.

Work therefore was transferred to an amateur station W2AG located in Yonkers, N. Y. This station was equipped by its owner, C. R. Runyon, to operate on 110 megacycles and was used to demonstrate the system to the Institute of Radio Engineers in November 1935, on the occasion of the presentation of a paper[1] describing the system.

Next, application was made to the Federal Communications Commission for permission to construct a high-power 40-megacycle transmitter the success or failure of which would remove from the realm of academic discussion all questions concerning the efficacy of the system. The necessary authority was obtained at the end of 1936 and construction was started in the spring of 1937. The erection was completed and testing started in the fall of 1938. In the intervening time scores of demonstrations carried out from the Yonkers station, W2AG, were made to the representatives of the broadcast industry. As a result of these the Yankee Network decided to enter the field and proceeded with the construction of a station near Worcester, Mass. (Mt. Asnebumskit, Paxton). At about the same time, the management of Station WDRC at Hartford, Conn., entered the field with the erection of a station on Meriden Mountain, Meriden, Conn. Shortly thereafter the General Electric Company, as a result of the W2AG demonstrations, became interested and carried out and published the results of a long series of tests confirming the conclusions arrived at during the Empire State field tests.

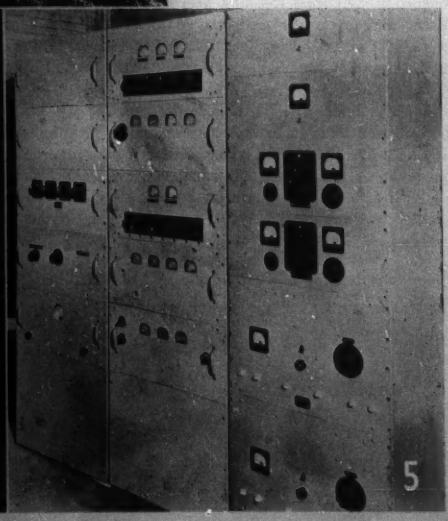
The Alpine transmitter was ready for preliminary testing during the summer of 1938. All expectations were more than fulfilled and in the summer of 1939 the sta-





Figures 3–6. Frequency-modulation transmitter built at Alpine, N. J., by the author during 1937–38; note antenna between extremities of two upper arms (3), antenna structure, after a sleet storm (4), modulating equipment (5), frequency multipliers and low-power amplifiers (6)

Figure 7. Last two power - amplifier stages



tion was placed on a regular operating schedule. A general idea of the transmitter as originally installed is given by figures 3 to 7. Since height above the surrounding terrain is of primary importance in ultrahigh-frequency transmission, the site selected was on the cliffs on the west side of the Hudson River known as the Palisades. A point about 500 feet above the river 17 miles north of New York in the village of Alpine was chosen. The antenna structure of the Alpine station is illustrated in figures 3 and 4. The height of the tower above grade is 400 feet. The length of the three cross arms is 150 feet and their vertical separation slightly over 80 feet. The radiating members of the antenna consist of a series of seven pairs of crossed rods about 11 feet long which are mounted on a boom supported between the tips of the two upper arms. These crossed rods or "turnstiles" are separated slightly less than half a wave length and are fed by a series of transmission lines which wind around the supporting member. The whole antenna is fed by an open-wire transmission line of about 500 ohms impedance which runs vertically through the center of the tower and horizontally over to the transmitter building for a total distance of about 700 feet. The efficiency of transmission appears to be of the order of 90 per cent.

The modulating equipment, similar in type to the "bread board" setup of figure 1, is shown in figure 5. The modulator is entirely contained in the center rack, the left-hand rack housing the ordinary line amplifiers, and the right-hand rack housing the power-supply equipment for operating the modulator and other units. Figure 6 shows a further series of frequency multipliers and low-power amplifiers for raising the power to a level of 1 kw at 40 megacycles. The last two power stages employ water-cooled tubes which raise the power respectively to 3 kw and to 40 kw. Figure 7 shows these amplifiers as installed in a shielded cage, which is necessary for the protection of the operating staff from the high field strength. The modulating and low-power units shown in these illustrations were built by the Radio Engineering Laboratories and the two high-power amplifier units by the RCA Manufacturing Company.

In the summer of 1939 the Paxton (figure 8) and Meriden transmitters were completed; and when they and the Alpine transmitter were placed on a regular operating schedule so that their performance could be observed daily, the broadcasting industry became convinced that a change was imminent. A dozen more stations were constructed and applications for over 150 more were on file with the Federal Communications Commission by the fall of 1939, when it was alleged that improper standards were being employed and that a band width narrower than 200 kilocyles could be employed more effectively. The granting of further construction permits was suspended pending an investigation by the Commission of this question and the question of providing additional channel space to accommodate the large number of applications for licenses. A public hearing by the Commission in March 1940, resulted in the approval of the 200-kilocycle band, the rearrangement of the allocation plan to increase substantially the assignment of channel space (42–50 megacycles) and the decision to grant commercial licenses. The Communications Commission has now resumed the issuance of licenses, and some 15 permits for commercial instead of merely experimental operation, have now been granted.

Figure 9. Winter condition of experimental frequency - modulation antenna atop Mount Washington, N. H.

Figure 8. Interior of Paxton, Mass., transmitter building

RELAYING

At the present time the wire-line facilities available for linking radio stations into networks are limited to the transmission of a frequency range up to about 5,000 or 6,000 cycles and have a residual noise level considerably greater than that required for the full dynamic range of even ordinary studio orchestral productions. Approximately the same limitation is imposed on the present-day radio stations by the lack of available frequency space and by the noise problem which results when receiver circuits and speaker systems are adapted to reproduce the full audio range of 15,000 cycles. These limitations are not imposed on the frequency-modulation system since the band width used is much in excess of the range of frequencies to be transmitted and the low noise level permits

the effective reproduction of the weakest overtones. Residual noise in the transmitting equipment is now better than −70 decibels, so that the signal-to-noise ratio over a large part of the service range of a high-power station can be held below this level. Since the bottleneck, at the present time and perhaps for a long time to come, lies in the wire connecting links, various radio relaying projects have been started.

The first of these was initiated by the Yankee Network to transmit the programs originating in its Boston studios to the top of Mt. Asnebumskit. The air-line distance is approximately 45 miles. Preliminary estimates of the cost of construction of the type of wire line required were in the neighborhood of $70,000, with doubtful guarantees of the noise level. The problem was solved by the use of a frequency-modulated 250-watt 130-megacycle transmitter located on the roof of the six-story studio building, arranged with a directional antenna to beam the transmission toward Paxton. At the receiving end a directional array likewise adds to the efficiency of the circuit.

The initial cost of the installation was a fraction of the estimated cost of the line, its maintenance cost is negligible, and its performance far better than could be obtained with any line facilities that could be furnished, even at the cost mentioned. The circuit has been in operation for over a year and has functioned perfectly through even the heaviest thunderstorms. Experience with this circuit has indicated ways of cutting the cost markedly. A second relay project which the Yankee Network is carrying out is the construction of relay stations to rebroadcast the Paxton transmissions. The first of these to be erected is located at the summit of Mt. Washington in northern New Hampshire, about 130 miles from Paxton. For over six months of the year the climate at the summit of this mountain is one of the severest in the world, winds of over 200 miles an hour with extremely low temperatures being frequently encountered together with a type of ice formation that imposes great mechanical stresses on the antenna structures. Two years ago a 100-foot tower was erected and a small transmitter installed to determine the practicability of the operation of ultrahigh-frequency transmission from an antenna the normal winter condition of which is shown in figure 9. Two winters' experience has resulted in a solution of the problems involved and a one-kilowatt frequency-modulation transmitter is now installed on the mountain (to be increased to ten kilowatts in the spring); regular operation will begin about November 15. The performance of this station will be watched with much interest throughout the radio world. A similar station located on a mountain in northern Vermont will complete the coverage of the northern half of New England. Several similar networks are projected in the southern Atlantic and the Pacific Coast states.

Another relaying circuit is now in daily operation between Alpine, N. J., and Meriden Mountain, Conn., and Alpine and Helderburg Mountain, N. Y., the station of the General Electric Company near Albany. The distances involved are about 70 and 130 miles, respectively. At the Helderburg station reception is effected in the ordinary way, and the recovered audio signaling current at a remotely located receiver is sent over a telephone line to the transmitter where remodulation occurs in the ordinary manner. At the Meriden station the 42.8 megacycles of the Alpine transmission is converted to the Meriden frequency of 43.4 megacycles and amplified up to excite the final power amplifier without the necessity of creating any audio-frequency current in the process. It has been found possible to do this with the receiving antenna located within 100 feet of the transmitting antenna, and the elimination of the processes of detection and remodulation has resulted in the removal of the distortion incident to these operations.

The future undoubtedly will see the introduction of chains of relaying stations equipped with highly directional antenna arrays operating on frequencies considerably higher than those used in broadcasting.

TRANSMITTING AND RECEIVING EQUIPMENT

Great improvement and simplification has been effected in the design of both transmitting and receiving equipment since the building of the initial transmitter at Alpine. It has been found possible to eliminate the intermediate water-cooled power stage and to drive the final 50-kw amplifier directly by a 2-kw air-cooled amplifier stage, this in turn being driven by a pair of 250-watt high-amplification beam tubes, all operating on 40 megacycles. The beam tubes are readily driven by a pair of triplers operating with a power output of 10 to 20 watts. Perfectly stable and reliable operation is obtained with this arrangement of the exciter stages. Figure 10 shows a complete modulating and exciter unit (2 kw). Figure 11 shows the 50-kw amplifier unit for the Paxton station during construction. These units together with the power-supply racks for the high-power amplifier are all that is required for the production of 50 kw of frequency-modulated power.

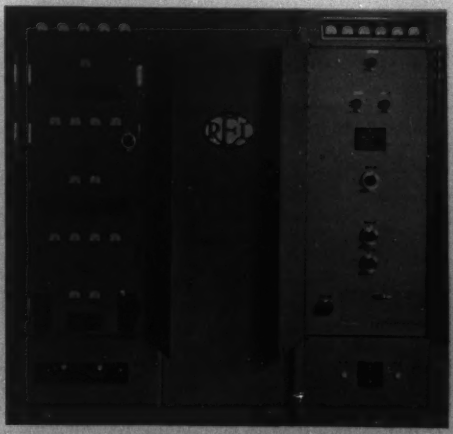


Figure 10. Modulating and power amplifier units of complete two-kilowatt transmitter

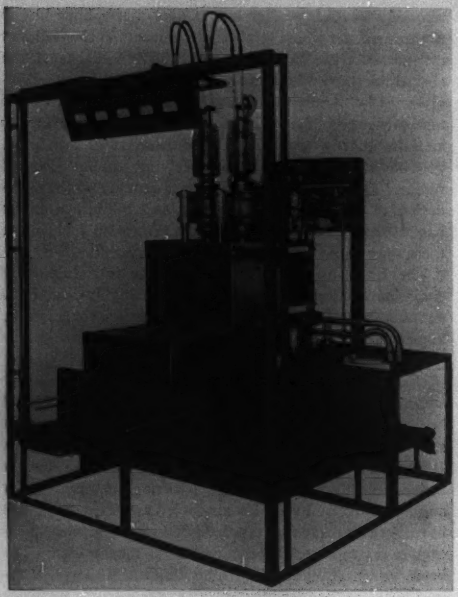


Figure 11. Power-amplifier unit of 50-kw frequency-modulation transmitter before mounting in shielded room

Similar progress has been made in receiver design, figure 12 showing a general-purpose receiver which operates effectively on a field strength of about ten microvolts per meter and gives an undistorted audio output of about 15 watts (a few watts only is necessary for home reception). Ten tubes are used, but with the production of double-purpose tubes specially designed to meet the requirements of this type of receiver further reduction in the number of tubes and parts is possible.

At the present time intensive commercial development of both transmitting and receiving equipment is under way, the General Electric Company and the Western Electric Company being now in position to supply transmitters and some dozen receiver manufacturers having on the market sets adapted to receive both the frequency-modulation and standard-broadcast amplitude-modulation transmissions.

SOME UNIQUE CHARACTERISTICS

There are some characteristics that are unique in the frequency-modulation system which have no counterpart in amplitude modulation. It is, of course, well known that when the carriers of two amplitude-modulated transmitters are sufficiently close in frequency to produce an audible beat, the service range of each of them is limited to that distance at which the field strength of the distant station becomes approximately equal to one per cent of the field strength of the local station. As a consequence, the service area of each station is greatly restricted; in fact, the service area of the two stations combined is but a small percentage of the area rendered useless for that frequency by the presence thereon of the two interfering stations.

With the wide-band frequency-modulation system, however, comparable interference between two transmissions does not appear until the field strength of the interfering station rises to a level of between 25 and 50 per cent of the field strength of the local one. The reason for this lies in the fact that while the interfering signal, in beating with the current of the local station under such conditions, may be producing a large change in the amplitude of the voltage applied to the current limiter, the system is substantially immune to such variations in amplitude. The only way in which the interfering signal can make its presence manifest is by superimposing some modulation of frequency on the frequency variations of the local signal. Under the conditions this "cross modulation" or phase shift superimposed upon the signaling current is limited to something of the order of a 30-degree change in phase, and the characteristics of the wide-band receiver are such that at least within the range of best audibility a phase shift of thousands of degrees in the signaling current is necessary to produce full modulation. Hence the 30-degree interfering phase shift superimposed upon the signaling current will produce little change in the rectified or detected current. As a consequence, the interference area in territory served by two frequency-modulation stations on the same channel is greatly reduced, as compared with amplitude modulation, and becomes, in fact, less than the area usefully served.

This property of the system, coupled with the fact that the propagation limits of ultrahigh frequencies are more sharply defined than those of the present broadcast frequencies, makes it possible to operate stations occupying the same channel space with much less geographical separation. Where desirable, it will be found practical to operate stations from 25 to 50 miles apart.

Figure 12. General-purpose frequency-modulation receiver having an undistorted audio output of about 15 watts

There is likewise a fundamental difference in the factors that govern distortion in the amplitude- and frequency-modulation equipment. Provided the circuit constants are properly designed for the frequency of the signaling currents, distortion in an amplitude-modulated transmitter or receiver depends principally on the linearity of the characteristics of the vacuum tubes employed. In frequency modulation, distortion is practically independent of the linearity of all the tubes that handle radio-frequency current and is dependent only on the phase shift introduced by the circuit components. These can be more readily designed and maintained to keep distortion below a desired limit. As a consequence, not only can aural effects be transmitted and reproduced with great fidelity, but the system is well adapted for multiplexing. It has been found possible to transmit simultaneously both an aural and facsimile program without interference between the two, the facsimile transmission being carried out on a channel of superaudible frequency. This was accomplished as early as 1934 over a distance of 85 miles in the original tests using the two-kilowatt transmitter at the Empire State Building in New York.

APPLICATION TO SERVICES OTHER THAN BROADCASTING

The system has important applications to various types of emergency communication services. Since the transmission of intelligible speech requires a much smaller range of frequencies than the full musical range—in fact a range of perhaps only 250 to 3,500 cycles—a smaller deviation of the transmitted frequency may be employed. It has been found practicable to make use of a total band width of 40 kilocycles in police service, and several installations are now operating effectively.

The largest project at the present time is that undertaken by the Connecticut State Police, who have in operation nine fixed stations and approximately 200 mobile stations equipped for two-way operation. The fixed stations are located on hill tops and have 250 watts power output. The car transmitters have approximately 25 watts power output. Thirty-mile communication between the cars and the fixed stations and five- to ten-mile communication between cars is easily obtained. This system was designed by Professor Daniel E. Noble (A'32) of the University of Connecticut. (See figures 13 and 14.)

The next largest project to be undertaken is in the city of Chicago, where some 200 mobile 25-watt car units are being installed. Numerous other projects for police

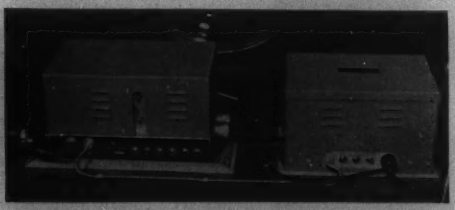


Figure 13. Transmitter (left) and receiver in rear interior of car, Connecticut State Police system

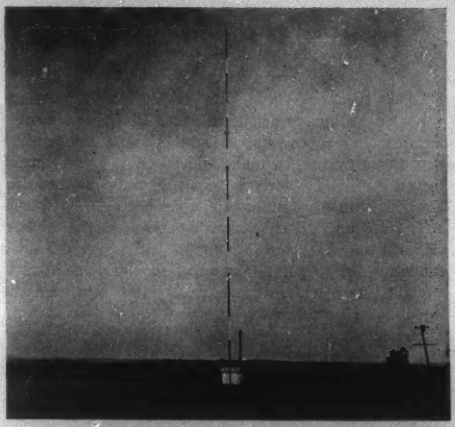


Figure 14. Connecticut State Police system: two-way 250-watt station at Wilton, Conn.

services and for emergency-service use by power companies are being made, and it is doubtful if many new installations employing amplitude modulation will be made in the future. It is, of course, needless to say that there are many important military uses. In fact, in practically all ultrahigh-frequency applications where weight or portability is not too great a factor, the frequency-modulation system has found increasing use. The one important field where progress has been inexplicably slow has been television, where its advantages, particularly on the sound channel, could be effectively utilized. A limited use has been made in the relaying of the television sight channel.

CONCLUSION

Five years ago the writer said[1] that "the conclusion is inescapable that it is technically possible to furnish a broadcast service over the primary areas of stations of the present-day broadcast system which is very greatly superior to that now rendered by these stations." With the cost of transmitting equipment for the new system already below the cost of the equipment of the standard broadcast type (for the same power output) and with the cost of broadcast receivers approaching levels that will permit large-scale production and distribution, the conclusion is likewise inescapable that within the next five years the existing broadcast system will be largely superseded.

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Traffic Safety Lighting on the Pennsylvania Turnpike

FOUR types of illuminants—high-intensity mercury-vapor, sodium-vapor, fluorescent, and incandescent—are used for various types of lighting applications on the new Pennsylvania Turnpike which recently was opened to traffic. First important "super highway" in America, the new turnpike stretches 162 miles between Pittsburgh and Harrisburg, Pa., burrowing through the highest ridges of the Allegheny Mountains with seven mile-long tunnels. More than 110 miles of the four-lane road is straight, the maximum grade is three per cent, and the worst curve is six degrees.

Mercury-vapor lamps are used in lighting the seven tunnels, said to be the first tunnels ever lighted by this type of lamp; sodium-vapor lamps are used at the tunnel approaches and at traffic interchanges; fluorescent lamps are used inside the ticket offices, and incandescent lamps under the marquees over the driveway spaces at ticket offices. The lighting equipment was supplied by the Westinghouse Electric and Manufacturing Company.

Employing 1,060 250-watt high-intensity mercury-vapor lamps in open reflectors recessed into tunnel ceilings, the tunnel-lighting system is said to provide three times as much light output as could be obtained from incandescent sources of the same wattage. The lamps are mounted horizontally with their long axes parallel to the roadway. Intensities at the tunnel ends are of the order of 150 foot-candles, tapering down to $5^1/_2$ foot-candles at some 250 feet from the entrances. Such gradation eases the reaction of the motorists' eyes in going from daylight to the much lower illumination level in the tunnels. The tunnel lighting is designed for a driving visibility of well over 1,000 feet.

Emergency lighting systems operating from batteries also are provided for the tunnels. Emergency fixtures are spaced 300 feet apart in alternate rows, and furnish sufficient illumination for discernment of normal hazards. The seven tunnels are served by 242 emergency units. Batteries and controls are housed in control rooms at the tunnel portals. If the main power supply to any tunnel is interrupted, the emergency system automatically is placed in operation. The batteries are charged by gasoline-engine-driven generators, so that the length of time that the emergency lighting systems can function is limited only by the gasoline supply.

The tunnel-approach lighting extends an average of 1,800 feet out from the tunnel portals and employs 10,000-lumen sodium-vapor units. These lamps not only provide a good seeing light, but also act as caution signals. Luminaires are spaced at gradually increasing intervals, from 125 to 350 feet, progressing away from the tunnel portals. This lessens the contrast between the bright tunnel lighting and the comparatively dim illumination of automobile headlights when leaving a tunnel, and accomplishes the reverse effect when approaching a tunnel.

At traffic interchanges, sodium-vapor units are used not to supply high intensities, as at the tunnel entrances, but for cautioning approaching motorists. For this purpose 151 sodium-vapor units are used, an average of 14 per interchange, being placed at strategic points where caution signals are desirable—on turnouts, curves, and underpasses.

In each ticket office, four 40-watt white fluorescent lamps provide an intensity of 45 foot-candles on the ticket-sellers' desks. Outside areas under the marquees which cover the driveway spaces are illuminated by incandescent units flush-mounted in the marquee ceilings. Six luminaires are used at every drive entrance, five of which are 200-watt units.

Each mercury-vapor lamp in the tunnels operates from an individual transformer, supplied from a 2,300-volt 60-cycle multiple circuit. The sodium-vapor lamps are connected in series on constant-current circuits through 6.6-ampere regulators. Other lighting units are fed from parallel circuits through distribution transformers. Total lighting load is 375 kw, and is supplied by four companies along the route.

Entrance to one of the Pennsylvania Turnpike tunnels

Instrument Landing of Aircraft

Development of equipment for instrument landing of aircraft, popularly known as "blind" landing, has progressed to the point where ultrahigh-frequency radio landing equipment is to be installed at ten important air terminals throughout the United States by the Civil Aeronautics Administration. An extended period of service testing and pilot training will follow, and still further development is expected before such equipment is ready for use in regularly scheduled commercial flights. Experiments also have been made with a so-called micro-wave system using yet higher frequencies. The features of both systems are outlined briefly in this article, and three types of indicating instruments are described.

NOT many years ago, unfavorable weather conditions meant the cancellation of all aircraft flights. Subsequent development of radio aids to air navigation have made it possible for an airplane to *fly* with safety under conditions of poor visibility, but it still is necessary to cancel flights where conditions at the airport of destination are such that the pilot cannot see to land. The problem of *landing* an airplane under adverse weather conditions remains the most important problem in commercial flying today. The United States Civil Aeronautics Authority (now Civil Aeronautics Administration), realizing this to be the bottleneck of safe flying under conditions of low ceiling and poor visibility, has endeavored to overcome the difficulty by fostering the development of a suitable instrument landing system.

For more than ten years, experiments have been under way with various types of systems, but the most promising ones today are those utilizing ultrahigh-frequency radio waves. An experimental system of this type embodying the latest advances in the art was installed during 1938–39 at the Indianapolis, Ind., airport under auspices of the Civil Aeronautics Authority.[1] The performance of this equipment was so satisfactory that the Authority decided, early in 1940, to proceed with the installation of similar equipment at ten important airports throughout the United States. An extended period of service testing will follow.

Another system, similar to the Indianapolis system but utilizing higher frequencies and known as the micro-wave system, has been developed at Massachusetts Institute of Technology.[2]

Instrument-landing systems have been developed also by the National Bureau of Standards, the United States Army, Air-Track Manufacturing Corporation, Bendix Aviation Corporation, and other organizations. Only the so-called Indianapolis and micro-wave systems are discussed here, however, a description of all the systems obviously being outside the scope of this article.

ESSENTIALS OF ULTRAHIGH-FREQUENCY SYSTEMS

To make an instrument or "blind" landing, an airplane pilot must be provided with lateral guidance, vertical guidance, and position "fixes." Lateral guidance is necessary to enable the plane to land in the middle of the runway. Vertical guidance and position "fixes" combine to guide the plane to a landing point on the runway at the proper rate of descent, and to prevent overshooting or undershooting the runway. In the systems described in this article, four separate radio transmitters are required to provide this information: one for lateral guidance which produces the so-called localizer beam; one for vertical guidance which establishes the so-called glide path; and two for position fixes which provide vertical "marker beacons", one at the airport boundary and one about two miles from the boundary on the approach side. Special antenna arrays have been devised to produce beams having the desired characteristics. A complete set of four transmitters is required for each landing direction, except where the equipment is portable and can be shifted from runway to runway.

On the airplane, three separate radio receivers are used, one to receive the localizer beam, one the glide-path beam, and one the marker-beacon signals. Signals from all three transmitters are translated into appropriate impulses and applied to suitable instruments which provide the pilot with the necessary landing information. The procedure in making a typical instrument landing is outlined in figure 1.

Principal features of the Indianapolis and micro-wave systems are outlined briefly in succeeding portions of this article. Instruments developed for use with these systems also are described, as well as an instrument known as the "Flightray" developed by the Sperry Gyroscope Company.[3]

EQUIPMENT ON GROUND—INDIANAPOLIS SYSTEM

Four complete groups of transmitters have been installed at the Indianapolis airport, permitting instrument landings in any one of four directions (figure 2). All transmitters are connected to a monitor and control desk in the airport control tower by telephone lines so that the four transmitters for any of the landing directions can be turned on as required to meet local wind conditions. Calibrated instruments and signal lamps give qualitative and quantitative indications from the various transmitters. If the output of any transmitter should fall below a predetermined level, visual and aural alarms will indicate the trouble. Alarms also will operate if the runway localizer course should shift sufficiently to cause an airplane following the course to land off the runway. The Indianapolis

Much of the text and most of the illustrations in this article were drawn from two AIEE papers listed as references 1 and 2 at the end of this article and the Institute of the Aeronautical Sciences paper listed as reference 3. Special acknowledgment is made to P. D. McKeel, acting chief, radio development section, technical development division, Civil Aeronautics Administration, who supplied the diagram forming the basis of figure 1, together with the associated explanation.

1. For all numbered references see list at end of article.

equipment was developed and installed by the International Telephone Development Company.

Localizer Installation. Equipment for producing the localizer beam consists of a transmitter, antennas, modulator, and associated equipment, all housed in a wooden building approximately 12 feet square located off one end of the runway.

The localizer transmitter has an output of 300 watts, unmodulated, at a frequency of 109.9 megacycles. It has a crystal-controlled oscillator followed by three frequency-

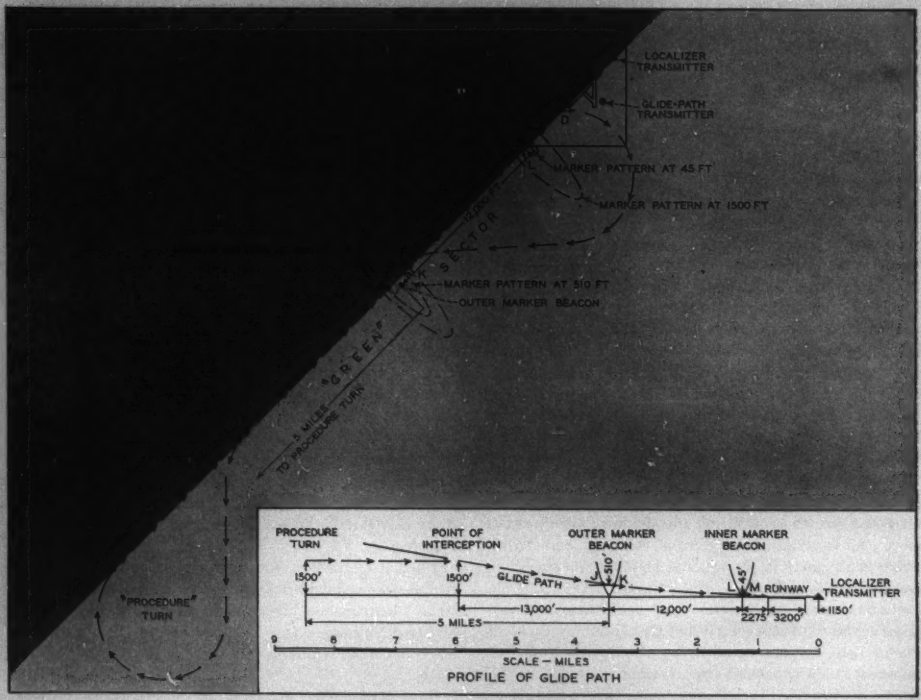

Figure 1. Diagrams showing how a typical instrument landing is made

The manner in which an instrument landing system operates can be illustrated by outlining the various steps required in making a typical landing. Suppose an airplane is approaching the airport at an altitude of 1,500 feet above the field from the left. Before beginning the descent, the pilot must maneuver his plane into proper position to intercept the glide path at the proper point and in the proper direction; then, by means of the information furnished by instruments on the airplane (see figure 13), this invisible pathway, produced by the electromagnetic fields radiated from the localizer and glide-path transmitters at the airport, guides the pilot to a safe landing on the airport runway.

After passing through the cone of silence or marker beacon at *A*, the pilot follows a course directly toward the airport. As the ship intercepts the field of the inner marker beacon at *B*, the pilot will observe audible and visual signals which continue to *C*. As the pilot proceeds along this course, the landing instrument will indicate that his ship is definitely in the "red" area of the localizer field. A definite and known time is required to fly this distance. Almost immediately after the inner marker beacon is passed, the instrument will indicate that the localizer course has been crossed (*D*). At this point, a "procedure" turn to the right is made, continuing until the plane again crosses the localizer course at *E*. The pilot then swings the ship into the localizer course and soon intercepts the field of the outer marker beacon at F_1 as with the inner marker beacon, visual and audible signals indicate when the ship has reached this point and continue to *G*. Tones of different pitch and visual signals of different color are used for the two marker beacons. From *G*, the pilot follows the localizer course for a distance of five miles, or to *H*, where the ship is swung left; a short flight in this direction is followed by a second "procedure" turn to the right, after which the localizer beam again is intercepted, at *I*. The plane now is in proper position to begin the descent (see profile diagram).

By keeping the plane on the course established by the localizer and glide-path beams, the pilot is able to bring the plane smoothly and safely to the airport runway. The beams radiated from the localizer and glide-path transmitters are received by the respective receivers on the airplane and are translated into visual indications that allow the pilot to follow the glide path with high accuracy. On the descent, the outer marker beacon signals again will be observed, between *J* and *K*; the altitude of the plane here should be about 500 feet, and the duration of the signals approximately 8 seconds. At *L*, the inner marker beacon signals will be observed; here, if the plane is descending properly, the altitude should be 45 feet and the signals will continue for $7\frac{1}{2}$ seconds (to *M*). Contact with the airport runway is made within a short interval after passing the inner marker beacon.

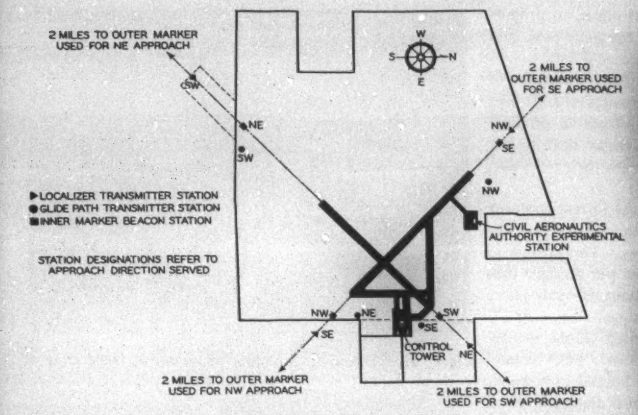

Figure 2. Plan view of Indianapolis, Ind., airport showing location of runways and instrument landing equipment

Figure 3 (right). Array of ultrahigh-frequency loop antennas used for the localizer beam at Indianapolis

multiplier stages to produce the output operating frequency. The last two stages are push-pull amplifiers operating at output frequency. A regulator holds the supply voltage constant within plus or minus one per cent for all normal variations of line voltage. Special precautions are taken to insure reliable operation during cold weather.

As few objects ordinarily found at an airport reflect horizontally polarized waves to the same extent that they reflect vertically polarized waves, the localizers are designed to radiate waves of the former type. To realize the advantages of horizontal polarization, a special antenna element was developed primarily for localizer use which radiates pure horizontally polarized waves in all directions. The field pattern in the horizontal plane is circular and in the vertical plane is figure-eight-shaped with zero radiation upward. Radiating systems with five antenna elements are used (figure 3), two of which are parasitically driven. The courses produced are entirely free of multiple courses and the bends in any of the courses do not exceed 0.15 degree, which is barely perceptible on the aircraft instrument. This antenna system produces two overlapping field patterns as shown in figure 4 which should give side indications of the guiding path that may be easily located at distances of 20 miles from the airport boundary. The field on one side of the runway center line is modulated at a frequency of 90 cycles per second; on the other side at 150 cycles. A mechanical modulator is used because of its inherent stability and freedom from aging. The courses are straight and reliably stable, maintaining their alignment to within one-tenth degree under all normal weather conditions.

Glide-Path Installation. The glide path is substantially a straight line from an altitude of 1,500 feet at a distance of five miles from the airport to the airport boundary; from there the path is slightly parabolic in shape, intersecting the runway surface at an angle of approximately one degree. The path passes over the outer marker beacon, two miles from the airport boundary, at an altitude between 500 and 700 feet. The method by which the constant-intensity glide path has been produced involves locating the antennas at a considerable distance to one side of the runway and forward along the runway so that the various points along the path appear in different directions as viewed from the antenna (figure 5). In this way, the angle subtended by the glide path, as viewed from the antenna, is opened so that it becomes possible by making

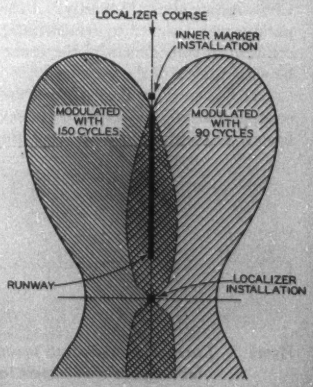

Figure 4. Field patterns from localizer antenna shown in figure 3

the antenna directive in the horizontal plane, to proportion the radiation along the extent of the glide path and control the height of the path at the various points.

The glide-path antenna system consists of two pairs of ultrahigh-frequency loops placed approximately 70 feet apart, fed in the proper phase and amplitude to produce the required pattern. The pair of antennas next to the glide-path-transmitter house, together with their reflecting screen, are shown in figure 6.

The glide-path transmitter is identical in construction and size with the localizer transmitter except that it operates on a frequency of 93.9 megacycles. The output is modulated at a frequency of 60 cycles per second, this modulation being accomplished by applying 60-cycle plate voltage to the two tubes in the output stage.

Marker-Beacon Installations. Five-watt 75-megacycle transmitters produce the marker beacons. Each transmitter and its associated equipment is housed in a small waterproof aluminum enclosure situated alongside of a wire-screen counterpoise 20 feet square over the center of which are two half-wave radiators mounted end to end. The radio-frequency carrier in the outer marker transmitter is modulated at a frequency of 400 cycles per second keyed so as to produce equal-length pulses at the rate of two per second. The inner-marker carrier is modulated at 1,300 cycles and keyed so as to produce equal-length pulses at the rate of six per second.

The marker installations are oriented so that the end-on radiators are parallel to the center line of the runway. In this way the major axis of the elliptically shaped pattern in the horizontal plane is at right angles to, and situated over, the runway center line.

EQUIPMENT ON GROUND—MICRO-WAVE SYSTEM

In general, the micro-wave system is similar to the Indianapolis system, except that the operating frequencies are in the neighborhood of 750 megacycles instead of 100 megacycles as at Indianapolis. Each system, of course, utilizes the best and latest techniques available for use with their respective frequencies. Experimental work with this system has been carried out by Massachusetts Institute of Technology under the sponsorship of the Civil Aeronautics Authority.[2] The experimental apparatus was designed to demonstrate feasibility only, but commercial embodiment of the results is now believed to be within reach of the industry.

The system in its present form uses frequencies of the order of 700 megacycles for both localizer and glide-path beams, although a localizer operating at approximately

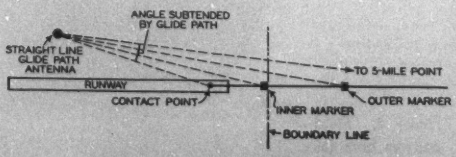

Figure 5. Location of glide-path transmitter and antenna at Indianapolis with respect to runway

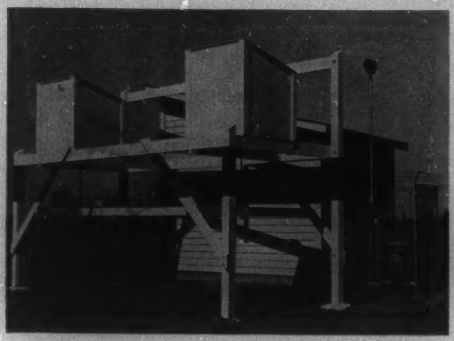

Figure 6. Glide-path transmitter house and antenna array at Indianapolis

400 kilocycles was used in some of the earlier tests conducted by M.I.T.

For most of the experimental investigations simple low-powered oscillators were employed as sources, using a feedback circuit with short sections of coaxial transmission line as circuit elements. These oscillators operated at wave lengths ranging from several meters down to the limit of oscillation of the tube used (about 40 centimeters) delivering about five watts at 50 centimeters and about one watt at 42 centimeters.

A comparative investigation was made of various types of antennas, parabolic reflectors, and horn radiators. On the basis of the results the horn type of radiator was selected because it was simpler to adjust, freer from spurious radiation from feed wires, and had inherently a better radiation pattern than was obtainable from the other devices examined. Like the lower-frequency system, horizontally polarized waves were found to have more uniform behavior with changing ground conditions than vertically polarized waves.

Making use of a theory of design evolved in a separate research program[4] a horn was constructed specifically for the production of a landing beam. The body of the horn was made of three-eighth-inch bakelite-bonded plywood and was lined inside with thin copper foil. Figure 7 shows the completed horn. It is about 26 feet long by 10 feet high by 2.5 feet wide (at the mouth) and has an angle of flare of 20 degrees in the direction of height. At a wave length of 50 centimeters this corresponds to a height of 6 wave lengths and a width of 1.5 wave lengths. The exciting antenna is a straight wire about one-quarter wave length long placed in the throat. Figure 8 shows measured radiation patterns of this horn in the vertical and horizontal planes under substantially free-space conditions. The vertical pattern is notably free from secondary lobes. The horizontal pattern has been made sharp, and the secondary lobes have been tolerated for sake of power gain. The preferred pattern in this plane, were less power gain satisfactory, would have a single broad lobe. A beam of this character could be obtained by reducing the width of the horn.

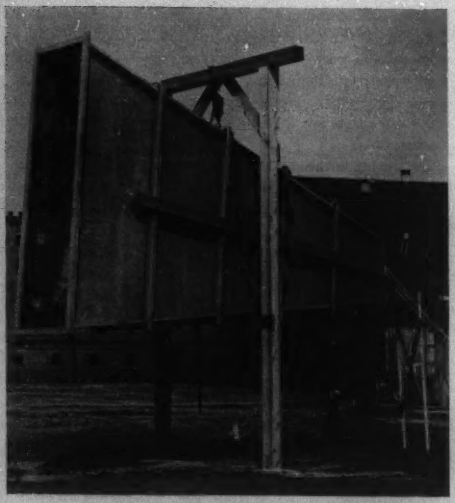

Figure 7. Electromagnetic horn radiator used in the micro-wave tests

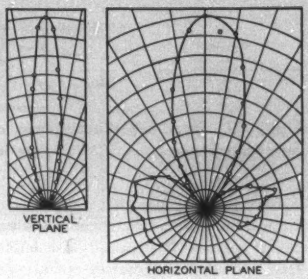

Figure 8. Field patterns in vertical and horizontal planes from the horn shown in figure 7

On the basis of preliminary tests, two horns of the type shown in figure 7 were set up with the lower edges of the mouths touching the ground; the angle of elevation of one was five degrees and of the other ten degrees. When transmitting with equal strength, these two horns yield a glide-path angle of about six degrees; a smaller angle is obtained by reducing the power output or modulation of the lower horn.

In the tests separate transmitters operating at slightly different carrier frequencies and modulated at 90 and 150 cycles per second, respectively, were used to excite the two horns, in order to avoid space interference of the carriers and to obviate any difficulty of cross modulation. Subsequent investigation has established a method by which a single source is used successfully. The use of separate oscillators is open to objection principally because it doubles the transmitting apparatus.

Flight tests made during September 1939 established the straightness of the micro-wave path over its entire length. A straight-line landing path at an angle of about three degrees with the ground was flown consistently over a distance of somewhat more than five miles. Using a transmitter having an estimated power output of 50 watts which was supplied to one horn, flight tests demonstrated that extremely strong signals were received at a distance of 25 miles and an altitude of 2,500 feet. This performance indicates that usable landing signals may be obtained at distances of the order of 50 to 75 miles.

EQUIPMENT ON AIRPLANE—INDIANAPOLIS SYSTEM

As indicated previously, the equipment on the airplane consists essentially of suitable apparatus to receive the three types of signals transmitted from the ground and to translate them into such form as will give visual indications to the pilot to direct him in making the landing. The equipment in most common use combines all three indications on the face of one instrument. The cross-pointer instrument was used in connection with the Indianapolis tests, and a cathode-ray type in the micro-wave tests.

On the cross-pointer instrument (figure 9) the vertical needle is actuated by the signals received from the localizer transmitter and the horizontal needle by those from the glide-path transmitter. When the ship is on course the vertical needle is in the vertical position, right or left displacement indicating that the ship is off course laterally; similarly, the displacement of the horizontal needle above or below horizontal indicates that the ship is respectively below or above the glide-path beam. The indications of both needles are such that when the ship is off course either way it must be shifted in the direction of the needle deflection in order to bring it on course.

Three indicator lights are operated from the output of the marker-beacon receiver. Two of these are used in instrument landing, one to indicate when the plane is over the outer marker and one when it is over the inner marker. The third light shows the pilot when the ship is over one of the fan markers located at important points along airways or over the towers of the radio range transmitting stations which are equipped with cone-of-silence markers (as at *A* in figure 1). The marker-beacon receiver is in continuous operation during the course of a flight, as it has other important uses in addition to its part in the instrument landing procedure.

One antenna, of the horizontal ultrahigh-frequency loop type, receives both runway localizer and glide-path signals. A horizontal dipole antenna mounted underneath the plane receives the marker-beacon signals.

Figure 9. Cross-pointer instrument

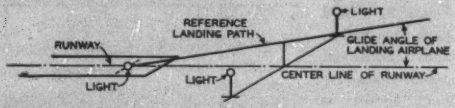

Figure 10. Hypothetical arrangement of lights on landing field representing basis of micro-wave indicating instrument

Both localizer and glide-path receivers are crystal-controlled fixed-frequency superheterodyne units. The localizer receiver is equipped with automatic volume control. To assure satisfactory operation under varying conditions, the glide-path receiver is provided with a voltage regulator, a ballast lamp, and temperature-sensitive elements.

The marker-beacon receiver also is a crystal-controlled fixed-frequency superheterodyne unit, and is arranged for both visual and aural indication of the signal being received. Three filters in the receiver separate the 400- and 1,300-cycle modulating tones of the instrument landing system, and the 3,000-cycle tone of the fan and cone-of-silence markers.

EQUIPMENT ON AIRPLANE—MICRO-WAVE SYSTEM

In developing a suitable instrument for the micro-wave system to be installed on the airplane, the problem was considered as illustrated in figure 10. If under conditions of no visibility it were possible to present to the pilot the same information that he would obtain were he to land on a clear night by means of three lights arranged on the landing field as shown, then a serviceable instrument landing system could be realized. These lights would indicate to the pilot in a simple, natural, and continuous manner not only the location but also the attitude and heading of his ship.

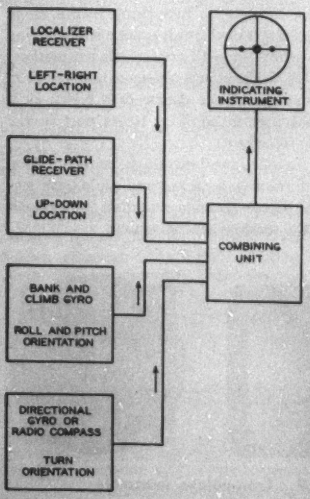

Figure 11. Block diagram showing method of combining indications from four sources to give a composite pattern on the micro-wave system instrument

This conception of the problem is due to Doctor Irving Metcalf of the Civil Aeronautics Authority, and is responsible in part for the undertaking of the micro-wave instrument-landing research by M.I.T., in that it demands much greater precision in the location of an approach path than appeared possible with the then-existing glide-path systems.

To visualize the problem in greater detail imagine that the three lights are seen through a transparent screen in front of the pilot. Assume that the screen has vertical and horizontal crosshairs intersecting at its center. When the airplane is in the proper orientation for landing, and is on the reference landing path defined by the three lights as shown, the pilot sees these lights equally spaced along the horizontal crosshair, the center light coinciding with the center of the screen. Any departure of the lights from this pattern on the screen indicates a corresponding departure of the airplane from the proper location or orientation.

In the simplest interpretation, the location of the light group indicates orientation and the relative configuration of the lights as a group indicates location. Thus turning of the airplane to the right or left moves the lights as a group left or right respectively; moving to the right or left of the reference landing path moves the image of the center light nearer to the image of the right- or left-hand light, respectively.

In the instrument developed, the cathode-ray tube is used to provide the indications. Information regarding orientation is derived from gyroscopic instruments on the

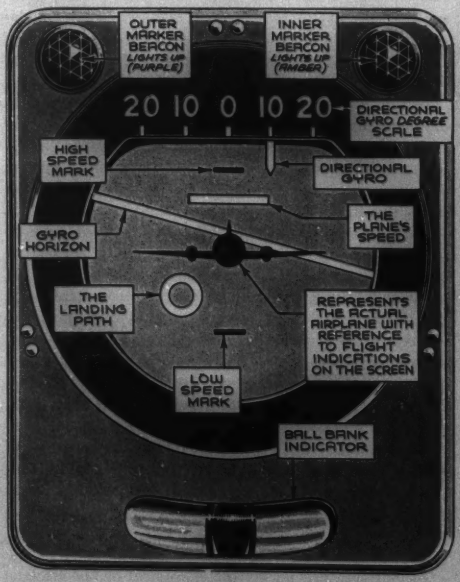
OUTER MARKER BEACON LIGHTS UP (PURPLE)
INNER MARKER BEACON LIGHTS UP (AMBER)
20 10 0 10 20
DIRECTIONAL GYRO DEGREE SCALE
HIGH SPEED MARK
DIRECTIONAL GYRO
THE PLANE'S SPEED
GYRO HORIZON
THE LANDING PATH
REPRESENTS THE ACTUAL AIRPLANE WITH REFERENCE TO FLIGHT INDICATIONS ON THE SCREEN
LOW SPEED MARK
BALL BANK INDICATOR

Figure 12. Face of Flightray instrument showing the various indications

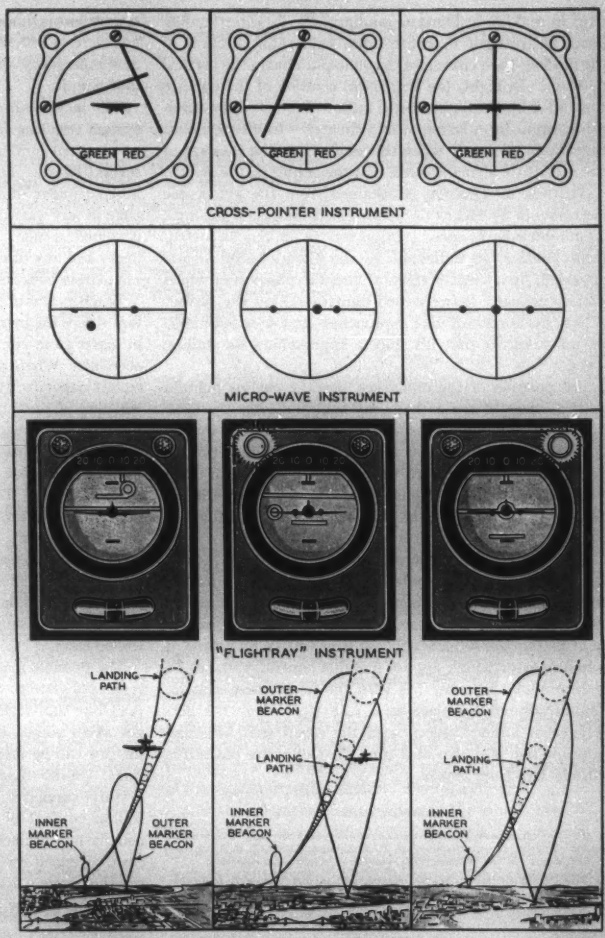

Figure 13. Typical indications on the three types of instruments described

Separate signal lights associated with the cross-pointer and micro-wave instruments indicate when the outer and inner marker beacons are passed

Left: Pilot is starting an instrument landing; ship below and to left of glide path

Center: Ship off path to right and beginning to descend; also passing outer marker beacon

Right: Ship on glide path and passing inner marker beacon; has but about one-half mile to airport runway

airplane; information regarding location is derived from the radio beams transmitted from the ground. The various indications are combined as shown in figure 11, and through a mechanical commutating device are impressed in rapid succession on the deflecting plates of a single-gun cathode-ray tube so as to give the visual appearance of a stationary pattern on the screen of the tube.

To obtain suitable indications from the gyroscopic instruments required the development of a simple electrical takeoff. Voltages thus obtained from the gyro instruments are sufficient to deflect the spots on the cathode-ray tube directly, and therefore amplifiers are not necessary.

The ultrahigh frequencies used necessitated the development of special equipment to receive the glide-path signals on the airplane. The received signal goes directly into a converter which mixes the signal with the third harmonic of the local 230-megacycle oscillator, producing a 10-megacycle beat-frequency signal. The beat frequency is fed to the intermediate-frequency amplifier where it is amplified with no greater difficulty than any other 10-megacycle signal. In the tests, an elaborate audio-frequency amplifier followed the superheterodyne receiver proper, incorporating four stages of resistance-coupled amplification with automatic volume control, a separating filter for 90 and 150 cycles per second, and separate one-stage amplifiers following the filter. The output of this audio unit is fed to the adapter unit of the cathode-ray indicator.

A control is provided to allow adjustment of the relative gain of the two audio channels. The setting of this control determines the angle of the glide path with respect to the ground, and the control may be set so that the approach-path angle is correct for a given type of airplane. This arrangement does not require a readjustment of the ground station to set the glide angle. The antenna is of the coaxial type, connected to the receiver by a one-quarter-inch copper coaxial line.

The cathode-ray indicating instrument also is useful during flight, the runway localizer signals simply being replaced by radio-beacon signals. It can be applied also to other landing systems; likewise, the micro-wave glide-path and localizer equipment can be used with other indicators, such as the conventional cross-pointer instrument.

THE FLIGHTRAY

Another cathode-ray instrument, developed by the Sperry Gyroscope Company for both instrument flight and landing, is known as the Flightray[3] (figure 12). When

used in making instrument landings, the localizer landing beam is arranged to control the horizontal position of the landing-path circle and the glide-path beam the vertical position. In flight, the horizontal position of the circle is controlled by the flight-course radio beacon, and the vertical position by a barometric altimeter. In either event, the ship is on course when this circle rings the fuselage of the miniature airplane outline in the center of the screen.

Attitude information is obtained from the gyroscopic instruments by means of simple electromagnetic pickups. As a knowledge of speed is important in making an instrument landing, an indication of the plane's speed also is provided, by a short horizontal line, the position of which varies vertically between two limit marks on the screen. When this horizontal line approaches the low-speed mark, the pilot knows that his ship is approaching its stalling speed.

The position of the miniature airplane outline painted on the screen of the cathode-ray tube indicates the position of the plane with respect to each of the four indications. When the plane is off course in any direction, it need only be flown toward the particular pattern to bring it back on course. Signal lights above the cathode-ray tube indicate when the ship passes over the outer and inner markers, one indicator for each marker.

As there are four separate indications on the face of the cathode-ray tube, switching is necessary, as with the instrument used in the micro-wave tests. To accomplish this, the various amplifiers associated with each instrument pickup are sequentially made operative by means of a commutator which applies suitable control voltages to each amplifier in turn. As with the micro-wave system, commutation takes place at a rate well above the persistence of human vision, with the result that although only one line is shown at a time the composite pattern is entirely free from flicker.

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Capacitors on a Growing System

THE capacitor is a very useful addition to the group of equipments and materials used on an electric distribution system. Its greatest value is that it increases the capacity of circuits carrying reactive load currents. A complete study of the optimum balance between capacitors and new circuit capacity also involves a study of saving in copper losses, improvement in voltage, which may or may not increase revenue, and a consideration of such factors as new emergency tie capacity that may be provided by a new circuit.

The increase in circuit capacity on any part of a power system resulting from capacitors, should not be valued as new capacity unless it will be necessary within a period of several years. There should be some tangible saving or postponement of investment for some definite period of time in any part of the system where increase in capacity is valued as such. Unless this is true, the saving in copper losses and any desirable voltage improvement are the only immediate benefits.

When evaluating saving in losses in the parts of the system where the increase in capacity is evaluated, the saving in losses from circuit additions should also be taken into account. When put on the basis of equal increases in circuit capacity, the increase obtained with a new circuit will save 50 to 60 per cent as much of the losses as that obtained with capacitors. For capacitors connected to a circuit at all times, the saving in losses may be readily estimated from a group of curves without knowing the original losses. The only characteristics of the load that need be known are the reactive kilovolt-ampere-hours supplied by a circuit and the approximate distribution of the reactive kilovolt-ampere load along that circuit. The saving in losses in a feeder main from three equal capacitor units will be within a few per cent of the saving when capacitors of the same total rating are distributed along the feeder main in the same way as the reactive load.

The possible increase in revenue will be small on a well-regulated system. In those extreme cases where the feeder is so long that regulators cannot maintain acceptable voltage at all points, the increase in voltage to make it satisfactory will be more important than the increase in revenue. Unless some special provision is made for control, a static capacitor has an effect on voltage at any point similar to that of a fixed booster. The fixed boost can usually be obtained with a fixed booster at a much lower cost. Capacitors, however, may be installed in preference to other system additions because they serve several functions whereas the alternative circuit additions serve only one purpose.

A study of some typical areas and loads indicates that the improvement of power factor with fixed capacitors on four-kilovolt feeders, to an ultimate value of 85 to 95 per cent will be justified. The higher power factor, in general, will apply to outlying residential areas, and the lower power factor, in general, to areas that are predominantly industrial.

On a large power system for the immediate correction of power factor to these limits in most cases would require a major investment which would not yield an immediate return. If capacitors are added to the power system as load in certain areas makes an increase of capacity necessary, they provide an effective means of adding capacity in small increments. These units will then be paying their way at all times until the optimum economic balance between investment in capacitors and other equipment is reached.

"Conclusion" of the first James H. McGraw Prize Paper for 1940 of the Edison Electric Institute, "Basis for a Program of Capacitor Additions on a Growing Distribution System," by V. G. Rettig (A'32), and published in the EEI *Bulletin*, August 1940, pages 387–94.

Some Notes on the 1940 National Electrical Code

ALVAH SMALL
MEMBER AIEE

Revised tabulations of allowable current-carrying capacities of conductors are among the many significant changes in the new 1940 edition of the National Electrical Code.* In this especially prepared statement, the chairman of the committee responsible for compiling the Code discusses these and other significant changes embodied in the new edition.

THE 1940 edition of the National Electrical Code, approved August 7 as an American Standard, is now being distributed; the indicated effective date is November 1. The publisher, the National Board of Fire Underwriters, expects a demand for over 300,000 copies, making this edition the "best seller" of the whole series of 21 editions beginning with the original 1897 text.

Recently it was claimed that in more than 650 political jurisdictions, state laws or municipal ordinances currently in force specify that wiring of premises for light, heat, and power must be installed according to the Code. In many other jurisdictions the Code is the basic text for local wiring regulations.

No important change was made in the editorial plan of the Code first used in the preceding (1937) edition; the chapter and article arrangement of that edition is continued except that the contents of chapters 9 and 10 have been transposed, the latter now containing tables and diagrams, and chapter 9 containing the few construction rules, so-called, thus far adopted.

A detailed analysis, listing all changes from the text of the 1937 edition, has been prepared by and can be obtained from the National Electrical Manufacturers Association (155 East 44th Street, New York, N. Y.). Many of the changes do not greatly modify the substance of the previous Code provisions. Quite a number of the changes are only to improve cross references.

Nevertheless, there are certain important changes of significance to those who supply, install, and employ electricity and utilization equipment. This brief article discusses some of these changes in the order of their appearance in the 1940 Code and without attempting evaluation of technical or economic importance.

The statement of the scope of the Code now excludes railways, as well as other utilities, so that the Code is not to be applied to electrical installations in railway property that are for facilities and purposes peculiar to the exercise of the utility function of the railway.

Several new definitions and changes in former ones add to clarity in applying some of the rules. It is the intent otherwise to employ the "Standard Electrical Definitions" and to have them apply throughout.

Details given in article 110, section 1111, as to working space about low-voltage equipment, indicate clearly that the Code deals also with the personal-injury hazard and not with the fire hazard only. In general, the intent was to have all the personal-injury safeguarding requirements of the National Electrical Safety Code for utilization wiring and equipment appear also in this edition of the National Electrical Code.

New section 1116 records another step in recognizing the use of mechanical devices, in lieu of or in addition to soldering, as a standard method for making conductor joints, taps, and terminals.

A number of changes in article 210, while adopted to secure safeguarding of a fire or casualty hazard, nevertheless, will bear importantly on the matter of adequacy of the installation as a whole. The Code proceeds conservatively in applying the police power in providing for adequacy for future uses of electricity.

In article 240 "Overcurrent Protection," paragraphs 2451–3 forecast general use by November 1, 1941, of a tamper-resisting, so-called type *S*, plug fuse, the products of all makers to be interchangeable.

Article 300 of chapter 3, "Wiring Methods and Materials," and related texts and tables in chapters 9 and 10, recognize three grades of rubber insulation for conductors of feeder and branch circuits. The classification is according to the operating temperature of the conductors. So-called code-grade rubber insulation (type *R*) is not to be employed where subject to temperatures higher than 50 degrees centigrade. This is the ambient-temperature limit specified in previous editions for whatever grade of rubber insulation was employed. The two new grades of rubber, types *RP* and *RH*, may be used with conductor operating temperatures of 60 and 75 degrees centigrade, respectively. They correspond generally to the performance and heat-resistant grades of rubber insulation that have been promoted for some years, but without Code recognition of their special properties.

CURRENT-CARRYING CAPACITIES

The familiar table 1, "Allowable Current-Carrying Capacities of Conductors," of previous editions of the Code is dropped. New tables 1 and 2 list current values for various sizes of conductors with these three grades of rubber insulation and for five other recognized classes of conductor insulation that may be employed in one or several of the standard wiring methods. Table 1 applies for three conductors in a raceway with two correction factors to be applied when a raceway contains up to six

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*Copies of the 1940 edition of the National Electrical Code (ASA designation No. C1-1940) are available at five cents each from the American Standards Association, 29 West 39th St., New York, N. Y.

or up to nine conductors, respectively. Table 2 applies to single conductors in free air. Both tables assume a room temperature of 30 degrees centigrade and correction factors are given for higher room temperatures, up to 140 degrees centigrade when asbestos is the principal component of the insulation.

This recognition of new grades of rubber insulation and the revised allowable current-carrying capacities of conductors are the products of investigations made under the auspices of a technical committee of the rubber building wire group of National Electrical Manufacturers Association, the initial and basic report of which is an AIEE paper by S. J. Rosch (AIEE TRANSACTIONS, volume 57, 1938, pages 155–67).

A notable change is the reduced allowable current-carrying capacities for conductors with code-grade rubber insulation and larger than 1,000,000 circular mils "in free air" and larger than number 8 AWG in raceways. These reductions contemplate "continuous" loads of the named values, a condition much more probable in modern wiring practice than was presumed with old table 1, whatever wiring method was employed.

The new tables 1 and 2, as was the case with former table 1, takes no account of voltage drop. Obviously, those laying out wiring systems must allow for it, especially when the calculated current loads on conductors produce operating temperatures approaching the permitted limits.

THIN-INSULATED CONDUCTORS FOR REWIRING

Present-day trends for improved illumination, especially in industrial and commercial occupancies, and the prohibitive cost of rewiring in some existing premises are recognized in paragraph (*e*) of section 3005 which allows: "Where in rewiring for increased load, space is not available in raceways" for conductors having standard thicknesses of insulation "and it is impracticable to increase the size of the raceway due to structural conditions," thin-insulated conductors with rubber insulation of the performance (type *RPT*) or the heat-resistant (type *RHT*) grades may be used; these insulations may be 1/32 inch instead of 3/64 inch in thickness for numbers 14 to 10 wire, inclusive—a reduction of 33 per cent. In addition, for the same small conductor sizes, the latex type of rubber insulation (type *RU*) that is not less than 0.018 inch thick may be used. This type of insulation is accepted for conductor operating temperatures not exceeding 60 degrees centigrade.

For these special conditions, paragraph (*e*) of section 3005 also recognizes conductors having "a flame-retardant, moisture-resistant approved solid synthetic insulation (type *SN*)" with a temperature limitation of 60 degrees centigrade in numbers 14 to 4/0, with an insulation thickness as shown in table in section 93001, no outer fibrous covering being required. The insulation thicknesses called for in this table are:

Conductor size (AWG number)	14–10	8	6–2	1–4/0
Insulation thickness (inch)	2/64	3/64	4/64	5/64

Except for numbers 6–2 these values are, in each case, 1/32 inch less (on the radius) than for rubber insulation on types *R*, *RP*, and *RH* wires. The omission of the fibrous covering further reduces the over-all diameter and cross-section area for a given size of conductor.

Another change provides recognition in numbers 14–8, inclusive, of conductors having the heat-resistant grade of rubber insulation (type *RHT*) 1/64 inch less (on the radius) in thickness than for types *R*, *RP*, or *RH* insulations and for general use wherever wires of these types are acceptable.

The foregoing changes recognizing new grades and reduced thickness of rubber insulation explains the requirement in paragraph (*f*) of section 3005 that "all rubber-covered conductors shall have a readily identifiable permanent marking to indicate the type of insulation."

Other articles in chapter 3 apply to specific methods of wiring. Former articles 326, "Surface Wooden Raceways," and 330, "Cast-in-Place Raceways," have been dropped. A new wiring method utilizing the hollow spaces in cellular steel floor construction is covered by the ten paragraphs of new article 356.

From 1897 to 1911 inclusive the National Electrical Code was produced under the auspices of the Underwriters National Electric Association. The 1913 and all subsequent editions have been sponsored by the National Fire Protection Association, which took over when the original sponsor was dissolved. The actual work of considering proposals for changes in the Code is in charge of the electrical committee, one of more than 40 technical committees of the NFPA. Beginning with the 1925 edition, the electrical committee has been so organized as to qualify as a sectional committee of the American Standards Association. Most editions of the National Electrical Code, beginning with that of 1920, have been approved American Standards.

From its large and varied membership, the National Fire Protection Association appoints members and alternates for service on the electrical committee representative of a cross section of the electrical industry concerned with its provisions. Over 100 such delegates were in attendance at the session in December 1939 when five morning and afternoon and three evening meetings were required to consider and act upon reports from over 60 subcommittees.

During May 1940, the committee's report was accepted by the National Fire Protection Association, which formally adopted the text of the 1940 edition of the Code as an Association Standard. This Standard was approved August 7 as an American Standard.

AIEE PARTICIPATION

The American Institute of Electrical Engineers has participated in the compilation of the Code with membership in the electrical committee since the National Fire Protection Association became the sponsor in 1913, and was previously a member of the so-called conference which reviewed the editions published by the Underwriters' National Electric Association. Members F. V. Magalhaes and H. S. Warren take important and constructive parts in the electrical-committee proceedings as AIEE representatives. In addition, many other members of the committee are AIEE members.

Nomography for the Electrical Engineer

GUIDO E. FERRARA
ENROLLED STUDENT AIEE

An outline of basic principles underlying nomographic charts, supplemented by examples illustrating their application to electrical-engineering problems

A RELATIVELY large amount of the work of calculation done by the engineer, designer, and student, consists of the repeated application of a certain number of formulas satisfying different conditions. When the number of variables entering into the calculation is large, or when the variables are raised to fractional powers, the difficulties and time involved may become very great. This process of repeated substitution can be greatly simplified by the use of nomographic charts.

A nomographic chart is the representation of an equation or formula in such a way as to provide a simple solution by simple mechanical means. Few books have been written on the subject, and articles appearing in technical publications have been restricted more or less to the presentation of just one particular formula. The fact is that the science of nomography is rather new—d'Ocagne (1884) gave it its name and developed the process of collinear points.

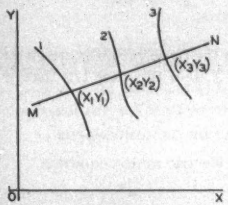

Figure 1

The utility and convenience of nomographic charts is obvious from the following brief summary of their principal advantages:

1. The number and variety of problems to which they can be applied is quite large.
2. There is no difficulty when the number of variables is large, or when the variables are raised to fractional powers.
3. Once the chart for any particular problem has been prepared, chances for errors are minimized.
4. The charts are simple and certain in use, so that calculations can be left to the care of unskilled subordinates.

PRELIMINARY THEORY

The mathematical foundation of nomography rests on the elementary theory of the third-order determinants. In the study of analytic geometry, a geometrical meaning was given to a third-order determinant. In figure 1, the line MN intersects the three curves 1, 2, 3, at points whose co-ordinates are (X_1Y_1), (X_2Y_2), (X_3Y_3). By similar triangles,

$$\frac{Y_3-Y_1}{X_3-X_1}=\frac{Y_2-Y_1}{X_2-X_1} \tag{1}$$

Or

$$Y_1X_2+Y_2X_3+Y_3X_1-Y_3X_2-Y_2X_1-Y_1X_3=0 \tag{2}$$

But, from algebra, it can be shown that equation 2 is the expansion of the third-order determinant

$$\begin{vmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{vmatrix}=0 \tag{3}$$

whence the theorem: If a third-order determinant has the value of 0 then the points (X_1Y_1), (X_2Y_2), (X_3Y_3) are collinear.

It is obvious then, that any equation which can be transformed into a form identical with equation 3 can be represented and solved by a nomographic chart.

EXAMPLES

Consider the equation

$$2x=3y+z \tag{4}$$

which can be written as a third-order determinant thus:

$$\begin{vmatrix} z & 0 & 1 \\ y & 1 & 0 \\ 2x & 3 & 1 \end{vmatrix}=0 \tag{5}$$

This determinant is not in the form of equation 3. It can be transformed, though, if one remembers a few fundamental theorems involving determinants, thus:

$$\begin{vmatrix} z & 0 & 1+0 \\ y & 1 & 0+1 \\ 2x & 3 & 1+3 \end{vmatrix}=\begin{vmatrix} 0 & z & 1 \\ 1 & y & 1 \\ 3/4 & x/2 & 1 \end{vmatrix}=0 \tag{6}$$

In this last form, the determinant is in nomographic-form arrangement. It can be seen that every set of values of z, y, and x satisfying equation 6 must have corresponding collinear points. Hence, the abscissa of z is 0, that of y is 1, and that of x is 3/4. The corresponding ordinates are the values of z, y, and x. So if the graduations of z and y are the same, then those of x are 1/2.

The nomograph corresponding to equation 6 is shown in figure 2. Any straight line drawn across the three scales intersects values of x, y, and z which satisfy the equation: $2x=3y+z$.

The same theory can be applied to equations in which

Essential substance of a paper presented at a student session of the AIEE Great Lakes District meeting, Minneapolis, Minn., September 28–30, 1939.

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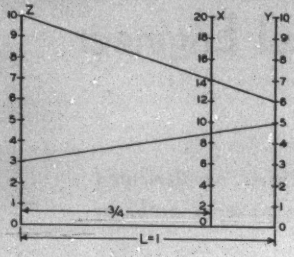

Figure 2 (above). Nomograph for equation $2x=3y+z$

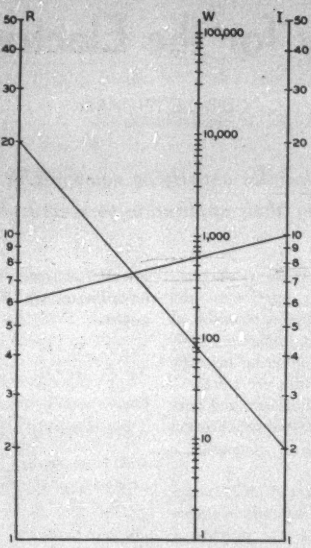

Figure 3 (right). Nomograph for equation $W=I^2R$

products or quotients are involved, for example, the familiar equation:

$$W=I^2R \tag{7}$$

This equation can be written also as:

$$\log W=2\log I+\log R \tag{8}$$

Equation 8 may be expanded into a third-order determinant thus:

$$\begin{vmatrix} \text{Log } R & 0 & 1 \\ \text{Log } I & 1 & 0 \\ \text{Log } W & 2 & 1 \end{vmatrix}=0$$

or

$$\begin{vmatrix} \text{Log } R & 0 & 1 \\ \text{Log } I & 1 & 1 \\ \text{Log } W & 2 & 3 \end{vmatrix}=\begin{vmatrix} 0 & \text{Log } R & 1 \\ 1 & \text{Log } I & 1 \\ 2/3 & \dfrac{\text{Log } W}{3} & 1 \end{vmatrix}=0 \tag{9}$$

Instead of using the linear scale for the ordinates of the variables, now a logarithmic scale should be used. The resulting nomograph is shown in figure 3.

Note that the graduations of I and R are three times as large as that of W. A little thought will show how to arrange the expanded determinant so as to get W on a different scale.

As a further example, the nomograph for the equation

$$Z^2=R^2+X^2 \tag{10}$$

has been constructed. This equation is familiar to the electrical engineer, Z representing the impedance of the circuit, R the ohmic resistance, and X the effective reactance.

It can be expanded into a third-order determinant, and put into nomographic form thus:

$$\begin{vmatrix} R^2 & 0 & 1 \\ X^2 & 1 & 0 \\ Z^2 & 1 & 1 \end{vmatrix}=\begin{vmatrix} 0 & R^2 & 1 \\ 1 & X^2 & 1 \\ 1/2 & 1/2Z^2 & 1 \end{vmatrix}=0 \tag{11}$$

In this case, the scale used on the ordinate of the variables is a "square" scale, the first interval being 1, the second 4, the third 9, etc.

The nomograph for equation 10 is shown in figure 4.

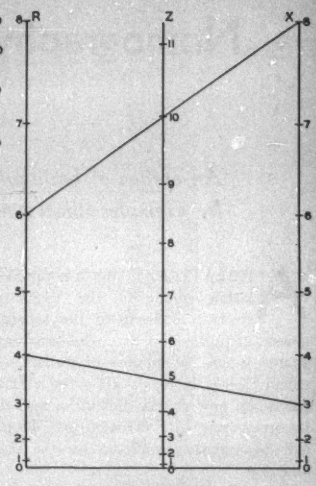

Figure 4. Nomograph for equation $Z^2=R^2+X^2$

The values of the abscissas for the three variables are given in equation 11. The scale of Z is in this case 1/2 that of X and R.

N CHARTS, OR COMBINATION OF NOMOGRAPHS

Consider the fundamental electric-motor equation

$$V_t=E_g+I_aR_a \tag{12}$$

in which V_t represents the terminal voltage, E_g the counter (or generated) electromotive force, and I_aR_a the armature voltage drop. This is a combination of equations 4 and 7 so that if we let

$$E_d=I_aR_a \tag{13}$$

the resultant equation is:

$$V_t=E_g+E_d \tag{14}$$

If we try to combine these two equations into a nomograph we can see at once that equation 13 yields results on a log scale while equation 14 yields results on a linear scale. Hence it is not advisable to construct a monograph for equation 13 by the method shown for equation 7. But equation 13 can be written in a third-determinant form thus:

$$\begin{vmatrix} R_a & 1 & 0 \\ 0 & I_a & 1 \\ -E_d & 0 & 1 \end{vmatrix}=\begin{vmatrix} R_a & 1 & 1 \\ 0 & \dfrac{I_a}{1+I_a} & 1 \\ -E_d & 0 & 1 \end{vmatrix}=\begin{vmatrix} 1 & R_a & 1 \\ \dfrac{I_a}{1+I_a} & 0 & 1 \\ 0 & -E_d & 1 \end{vmatrix}=0 \tag{15}$$

From the last determinant expression it can be seen that the abscissa of R_a is 1; those of I_a are $I_a/1+I_a$, and that of E_d is 0. Also, the ordinate of I_a is 0, which means that I_a lies on the X axis. Notice that E_d is negative; therefore it is plotted in the opposite direction from that of R_a. For sake of compactness we may plot the diagram on oblique axes with R_a and E_d in opposite directions,

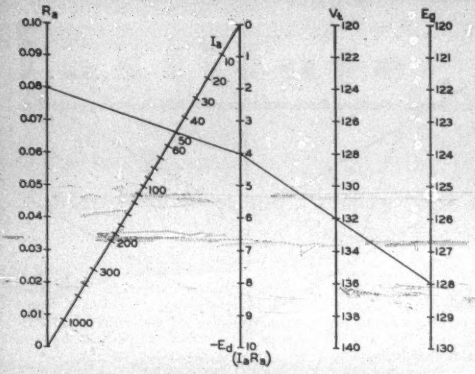

Figure 5. Nomograph for equation $V_t = E_g + I_aR_a$

and the zero points of R_a and E_g are joined by a diagonal. The graduations on this diagonal are projections of the abscissa $X_{I_a} = I_a/(1+I_a)$ which are laid off on the horizontal. The two nomographs are combined as shown in figure 5.

EQUATIONS WITH MORE THAN THREE VARIABLES

The method used in the foregoing examples can be applied to linear equations with more than three variables. Consider the equation of inductance L of a coil, given in terms of turns N, core permeability μ, area A, and length l:

$$L = \frac{4\pi N^2 \mu A}{10^9 l} \tag{16}$$

which can be written:

$$\log L = \log \frac{4\pi}{10^9} + 2 \log N + \log \mu + \log A - \log \tag{17}$$

Let

$$\log X = \log \frac{4\pi}{10^9} + 2 \log N + \log \mu \tag{18}$$

and

$$\log Y = \log A - \log l \tag{19}$$

Then:

$$\log L = \log x + \log Y \tag{20}$$

If equation 18 is expanded as a determinant, we can construct a nomograph and determine X. If the same process is used on equation 19 the resultant will be Y. Now if X and Y are plotted in series as given by equation 20, the final solution of L is obtained. For equation 18 we obtain:

$$\begin{vmatrix} \left(\text{Log } X - \text{Log } \frac{4\pi}{10^9}\right) & 1 & 1 \\ 2 \text{ Log } N & 1 & 0 \\ \text{Log } \mu & 0 & 1 \end{vmatrix} = \begin{vmatrix} 0 & \text{Log } \mu & 1 \\ 1 & 2 \text{ Log } N & 1 \\ 1/2 & 1/2\left(\text{Log } X - \text{Log } \frac{4\pi}{10^9}\right) & 1 \end{vmatrix} = 0 \tag{21}$$

For equation 19 we obtain:

$$\begin{vmatrix} \text{Log } Y & 1 & 1 \\ -\text{Log } l & 1 & 0 \\ \text{Log } A & 0 & 1 \end{vmatrix} = \begin{vmatrix} 0 & \text{Log } A & 1 \\ 1 & -\text{Log } l & 1 \\ 1/2 & 1/2 \text{ Log } Y & 1 \end{vmatrix} = 0 \tag{22}$$

Also for equation 20:

$$\begin{vmatrix} \text{Log } L & 1 & 1 \\ \text{Log } X & 1 & 0 \\ \text{Log } Y & 0 & 1 \end{vmatrix} = \begin{vmatrix} 0 & \text{Log } Y & 1 \\ 1 & \text{Log } X & 1 \\ 1/2 & 1/2 \text{ Log } L & 1 \end{vmatrix} = 0 \tag{23}$$

The nomographs for X and Y are plotted separately, and from them the resultant combination for equation 23 is constructed. The complete chart is shown in figure 6. Note that the X and Y axes are not graduated because they serve solely for the purpose of reference. Note also

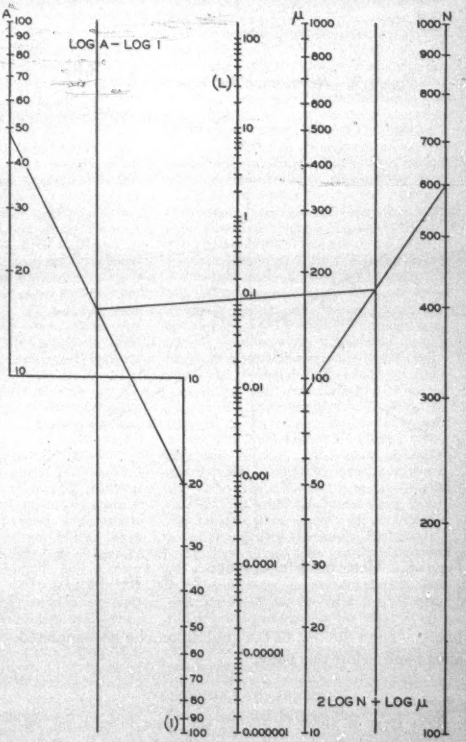

Figure 6. Nomograph for equation $L = \frac{4\pi N^2 \mu A}{10^9 l}$

that the constant log $(4\pi/10^9)$ was taken care of on the X axis. In fact, it did disappear there because the X axis is not graduated. The reader can analyze the complete chart and discover for himself that the same process can be applied to an equation involving any number of variables.

In order to graduate the scale of L, the following scheme was used: When the inductance is 1 henry, the turns 1,000, μ 500, and area 10, then the length is 62.83. Connect N and μ, and also A and l—(l is 62.83). Now connect the point of intersection on X with the point of intersection on Y, and where the line crosses the axis L mark 1

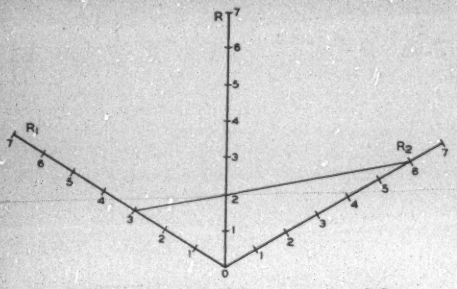

Figure 7. Nomograph for equation $R=\frac{R_1R_2}{R_1+R_2}$

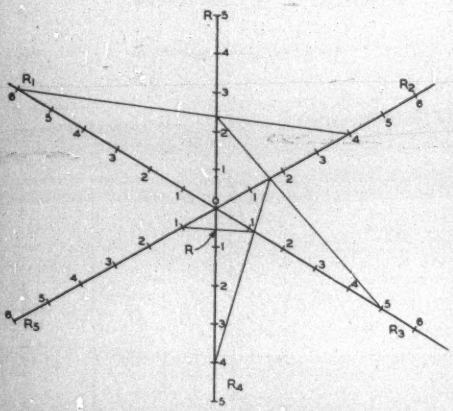

Figure 8. Nomograph for equation $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}+\frac{1}{R_5}$

henry. Then the rest of the graduation can be completed above and below this point.

CONCURRENT LINE CHARTS

This type of chart is one of the most interesting, especially for the undergraduate electrical engineer. It applies to equations in the form:

$$\frac{1}{R_1}+\frac{1}{R_2}=\frac{1}{R} \tag{24}$$

where R is the effective resistance across R_1 and R_2 in parallel. Rewriting the equation as $R_1R+R_2R=R_1R_2$ and expanding it into a determinant:

$$\begin{vmatrix} R_1 & 0 & 1 \\ 0 & R_2 & 1 \\ R & R & 1 \end{vmatrix} = \begin{vmatrix} 0 & R_1 & 1 \\ R_2 & 0 & 1 \\ R & R & 1 \end{vmatrix} = 0$$

we see that R is at an angle of 45 degrees with R_2 and R_1. By simple geometry, it can be proved that when the angle between R_1 and R_2 is 120 degrees with R bisecting this angle, the units of each axis may be made the same.

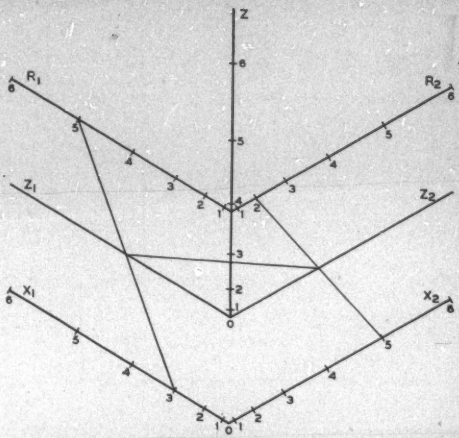

Figure 9. Nomograph for equation

$$Z=\frac{\sqrt{R_1^2+X_1^2}\ \sqrt{R_2^2+X_2^2}}{\sqrt{R_1^2+X_1^2}+\sqrt{R_2^2+X_2^2}}$$

Figure 7 shows the nomograph for two resistances in parallel. Figure 8 shows the same nomograph to be used when more than two resistances are in parallel.

Figure 9 represents an interesting combination of parallel-axes and concurrent-axes nomographs. The parallel-axes example of equation 10 was combined with the last method, so that one can solve for the impedances of each branch and obtain the value of the parallel combination with just one mechanical operation.

SUMMARY OF PROCEDURE

The foregoing examples show that the whole theory of nomography is embraced in the basic theory of third-order determinants. In order to apply this theory to the practical construction of nomographs, the following requirements should be satisfied:

1. Reduce the equation of a number of variables into one of only 3 variables.
2. Express the equation as a third-order determinant.
3. By proper manipulation arrange the determinant into another of nomographic form.
4. Represent the determinant by means of abscissas and ordinates properly scaled.

If the processes used in the foregoing examples are thoroughly understood, they should be sufficient to cover many of the common formulas used by the electrical engineer.

RELATED LITERATURE

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3. The Construction of Nomographic Charts, F. T. Mavis. International Textbook Company, Scranton, Pa., 1939.
4. Alignment Charts, W. J. Kearton, George Wood. Charles Griffin Company, London, 1932.

Institute Activities

A Wish For

A Merry Christmas and a Happy New Year

From President Royal W. Sorensen

"A Merry Christmas and a Happy New Year" is an old, old greeting but it is the very best wish your president can think of to send all Institute members as we approach that part of the year so interwoven with sacred American tradition. Indeed he would like to show his appreciation of the effective work all of you are doing for the Institute and our national defense program by sending every member a greeting card voicing the above message, supplemented by words of appreciation not only for that work, but also for the many things done to make his term of office so interesting and enjoyable. There are, however, so many of you (17,916) he must forego that desire and be content with the hope that every member will learn of his good intentions by reading this part of ELECTRICAL ENGINEERING.

Participation in Institute conventions, District, Section, and Branch meetings is a pleasant presidential duty requiring much time and travel. Your president since August 1st has attended the Pacific Coast convention, the Middle Eastern District meeting at Cincinnati; visited ten Sections and six Branches not in the Middle Eastern District; and has talked to an engineers' club, the Pacific Coast Electrical Association, and several college faculties. The ten Sections visited were: Alabama, Denver, East Tennessee, Georgia, Iowa, Louisville, Los Angeles, Muscle Shoals, San Francisco, and South Carolina. The Branches visited were those contiguous to the Sections noted. Secretary Henline and the president together visited all the places east of the Mississippi River included in the tour. At all these places the entire program was provided by your secretary and president.

Several outstanding impressions obtained from these visits are matters probably of interest for our members: The percentage of Section membership in attendance at all meetings was high; also, many of the meetings were attended by nonelectrical engineers. Attendance at the meetings frequently required many miles of travel by a rather large percentage of the membership. The Branches visited indicated that our engineering colleges have enrolled a satisfactory number of very capable young men who are being well trained to perpetuate and enrich the electrical engineering profession and continue the work of the Institute. These young men are effectively and enthusiastically conducting the work of the Branches. Indeed, the whole tour was an experience which I wish every Institute member could have, because he then would forever after be sufficiently enthusiastic about the work of the Institute to include in his activities a program of urging every electrical engineer to be a member of the AIEE.

In this connection, I am reminded of an experience a well-known engineer had when he was an engineering college senior. The president of his college gave a reception for all seniors, which several seniors, including the hero of this tale, failed to attend. Not only that, but, thinking he would not be missed, he neglected the courtesy of declining the invitation because of a previous engagement. The president, to give a lesson to all the seniors who had absented themselves from the reception without observing the formality of being excused, requested them to report at his office, where he listened to the excuses given and reprimanded them as his humor dictated. As the interview ended with the engineer about whom this statement is made, the president said: "Well, young man, you missed more than we did".

And so it is when electrical engineers engaged in the profession of electrical engineering fail to become AIEE members—the AIEE misses them but their loss is greater than that of the Institute.

We AIEE members should bear in mind that it is our duty to inform all electrical engineers, particularly the younger men, of the fact that in failing to accept the privilege of becoming members of the Institute, they are neglecting one excellent way of keeping abreast of the published advances in the profession, receiving the stimulus provided by a closer contact with men of outstanding achievement in the profession, and having the opportunity for discussing the technical papers published in ELECTRICAL ENGINEERING and the TRANSACTIONS. Indeed, as we older members survey the accomplishments and the personnel of our engineering profession, we are impressed by the fact that those responsible for electrical engineering achievements are very largely Institute members. Also, nearly all the relatively small number of successful electrical engineers who are not members of the Institute were once members for a considerable time, particularly during the period when they were advancing to high engineering and executive positions. When men who have reached high positions in industry and who let their membership lapse are discovered, we should encourage them to renew it in order that they may help the Institute give its members the benefits they obtained before they no longer felt the need of Institute membership. We also have observed that many of those who entered the engineering profession a score or more years ago and now have to their credit little professional engineering achievement are men who failed to appreciate the value of Institute membership and hence are not enrolled as members. It seems fairly logical, therefore, to conclude that Institute membership has much to do with the attainment of professional success.

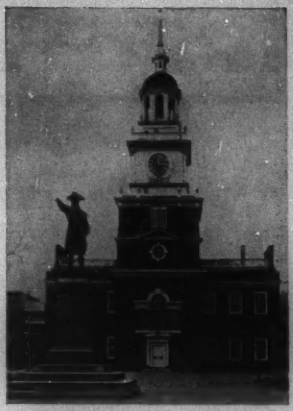
Having given this boost for the membership committee, may we discuss some other observations made on the president's initial tour of Sections.

As your secretary and president traveled from city to city, through villages and farming communities en route, we discussed with considerable pride the fact that every community appeared to be well provided with electric power lines. Furthermore, the unsettled and rural areas between cities and towns everywhere were spanned by these power lines, showing that for the most part these communities are not dependent solely upon a local or single source of power, but that cities and towns and even rural districts are interconnected thus making available everywhere under all conditions a ready and dependable power supply. Some of these electric power networks covering large areas are owned and operated by a single company. Others, while apparently unified physical networks, are made up in reality of several power systems joined by transmission lines, but each owned by independent and separate corporations, which because of the interconnections noted can sell to and buy from each other electric power according to need. Both plans appear to qualify alike in rendering reliable service to all who have need for electric power, be it the dweller of a small apartment using only a few lamps and a toaster, or an immense industry requiring thousands of kilowatts.

As these things were contemplated and we discussed our freedom to roam without question from city to city and state to state, and compared our lot with the restricted life of our friends across the seas, we were prone to become sentimental and say: Blessed is America, where men, though too much restricted in business, are still free to come and go and think and vote as they please and where co-operative efforts, such as are indicated by long power lines interconnecting power systems, may be carried on without international complications. Let us hope our situation in this respect will never change and that the present emergency conditions brought upon us by the actions of those in control of the affairs in other nations will soon be over. Let every member contemplate what engineering has done to make our standard of living what it is, and exert every effort to inform others that the true way to progress is through co-operation, which is the engineering way, rather than through narrow, nationalistic conquest, which is the emotional and unscientific way.

In the opening paragraph of this message, reference was made to the fact that Institute members are doing effective work in the national defense program. That statement was made because many engineers, particularly the younger ones, are frequently ask-

ing: "What can we do for national defense?" Our answer is: "Engineers are always developing and conducting national defense in the American way as they go about their regular daily occupations of providing things which improve our standard of living. Even in the present high-pressure and critical times only a few of us are now needed at Washington or at other special places where engineering designs are being made and engineering plans carried out. Those places for the present are well filled by some of our able and specially qualified members. Washington is provided with a list of our members and is being kept informed through the Institute office in New York about the occupation, residence, and special qualifications of our members. As need arises, the Institute will be requested to do any of the particular things needed in the defense program, some of which will be to recommend electrical engineers as needed. In the meantime, we can best serve by continuing our daily engineering occupation, whether that be research, design, manufacture, construction, operation, or study in college. Indeed, it is the hope of your president that when the time for the 1941 Christmas greeting arrives, much of the present furor will be over and the way will be clear for the free exchange of mutual greetings between all our members regardless of residence or citizenship. And may God grant that each such message will not be satire if it reads: "Peace on Earth, Good Will Toward Men."



Philadelphia Offers Historic Shrines and Variety of Industries in Convention Inspection Trips

INSPECTION trips to many nationally known industries and famous historical shrines will be an attractive feature available to those who attend AIEE winter convention to be held in Philadelphia, Pa., January 27–31, 1941. Other features will be a technical program of some 20 sessions of diversified interest, technical conferences, the Edison Medal presentation, a dinner-dance, and the usual smoker. Details of the technical program and further information are scheduled for publication in the January issue. Headquarters for the convention will be the Bellevue-Stratford Hotel.

Philadelphia has long been known as the "Workshop of the World," and is said to produce a greater variety of manufactured articles than any other industrial center. Metropolitan Philadelphia is noted for the production of steam and hydraulic turbines, electric switchgear and instruments, radio and television sets, storage batteries, locomotives, streamlined trains, ships, iron and steel, petroleum products, publishing, cigars and cigarettes, paper products, and textiles.

Philadelphia is also rich in historical interest. Convention visitors can see Independence Hall, the Liberty Bell, Congress Hall, Carpenters' Hall, the Betsy Ross House, Old Swedes Church, and other national shrines.

ADVANCE REGISTRATION REQUIRED

Co-operation with the National Defense Commission will require advance registration for inspection trips, many of which will be restricted to American citizens. About January 1 an inspection-trip registration card will be sent with other literature from AIEE headquarters, and must be returned promptly so that arrangements with the authorities can be completed. Instructions will accompany the registration cards.

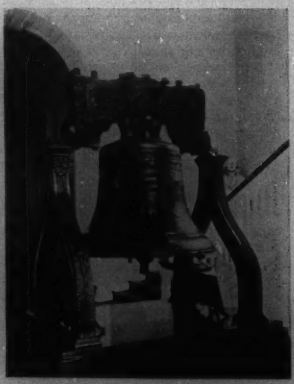
INSPECTION TRIPS

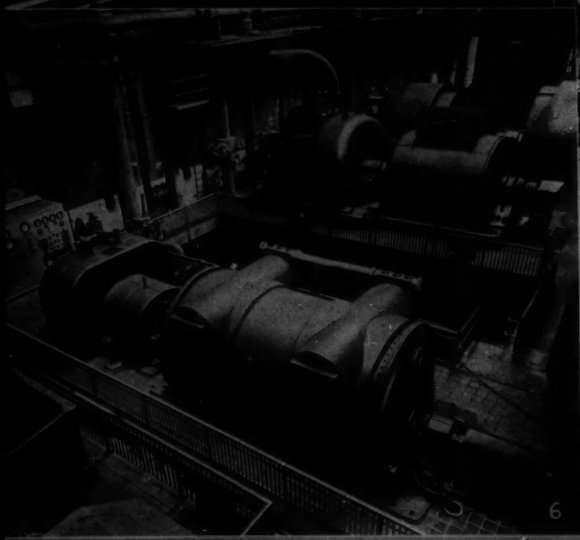
Historical and Civic Tours. These tours cover the historical, business, and residential sections of Philadelphia. Independence Hall, the Liberty Bell, the place of meeting of the first Supreme Court of the United States, the Betsy Ross House, and the spot where Benjamin Franklin flew his famous kite are among the points of interest which will be seen. Also, Fairmount Park, the University of Pennsylvania, and many other well-known landmarks will be visited.

Some Features of Winter-Convention Inspection Trips

This page: Independence Hall (above), the Liberty Bell housed in Independence Hall (lower right), the "flag room", where Betsy Ross was commissioned to make the first American flag (lower left)

Facing page: Building streamlined trains at the E. G. Budd Manufacturing Company (1), the Franklin Institute (2), air view of the Philadelphia switchgear works of the General Electric Company (3), high-power test laboratory of the I. T. E. Circuit Breaker Company (4), assembly-line production of radio receivers at the Philco Radio and Television Corporation (5), 50,000-kw topping turbine at the Schuykill station of the Philadelphia Electric Company (6), one of the newest locomotives operating on the electrified division of the Pennsylvania Railroad (7), turbine-electric tanker of the Atlantic Refining Company (8)





The Franklin Institute. Conceived and built as a lasting tribute to the memory of Benjamin Franklin, this unique scientific institution contains more than 4,000 action exhibits, most of which can be operated at the touch of a button. It has sections devoted to electrical engineering, aviation, chemistry, physics, transportation, and applied science. Many of the principles of electrical and mechanical equipment are demonstrated by action models which convention visitors may operate, including a full-size 265-ton locomotive valued at $100,000. In the planetarium, the sun and moon, planets and stars perform for the visitor no matter what the hour, the season, or the weather.

General Electric Company Switchgear Works. Visitors will see the latest developments in the switchgear art, products ranging from the smallest protective devices to the largest circuit breakers. The itinerary through the plant has been arranged to emphasize the results achieved by organized research co-ordinated with engineering, particularly with reference to oilless circuit breakers, high-speed protective relays operating on one cycle or less, modern testing facilities for voltages up to 3,000,000, modern safety types of vertical-lift metal-clad gear, and high-capacity station circuit-breaker equipment. At the conclusion of the shop trip, a technical demonstration and discussion of "Magne-blast" and air-blast circuit breakers will be given, supplementing the papers presented at the convention.

Westinghouse South Philadelphia Plant. Here turbines of all sizes, pumps, ejectors, high-speed forced-draft blowers, and lighting sets are built. The testing laboratory contains equipment for experimental and development purposes, particularly those problems relating to thermodynamics, aerodynamics, and hydrodynamics and for long-time tests to determine the behavior of metals when exposed to high temperatures.

Schuylkill Generating Station of Philadelphia Electric Company houses a 50,000-kw hydrogen-cooled turbogenerator (topping unit) designed for 3,600 rpm, 1,250 pounds pressure, 900 degrees Fahrenheit total temperature, and exhausting against a back pressure of 250 pounds supplied from two 600,000 pounds per hour pulverized-fuel-fired boilers. The switchhouse has recently been modernized and converted from a conventional double sectionalized bus installation to a six-section ring bus arrangement with oilless circuit breakers.

Philco Radio and Television Corporation. Here may be seen modern assembly lines for the production of radio receivers.

Pennsylvania Railroad Electrification. Opportunity will be given to inspect one of the latest electric locomotives designed for speeds in excess of 100 miles per hour and developing 8,500 horsepower; also the modern load dispatcher's office.

United States Mint is the oldest, largest, and best-equipped coinage plant in the world and the only mint open to the public. During the past year this mint produced coins for five foreign countries in addition to many millions of U. S. half dollars, quarters, dimes, nickels, and pennies. Here convention visitors will see the operation of the most highly developed modern machinery and also the largest and most valuable collection of coins and medals in the United States. All medals struck off at this mint are on display, including the Congressional Medal of Honor, medals for the Army, Navy, Marine Corps, and the medals awarded by Congress to Colonel Charles Lindbergh and Admiral Byrd. In addition, there are coins dating back to 2,000 years before the Christian era, including the "widow's mite" found near the site of the Temple of Jerusalem.

John B. Stetson Company. This factory is unique in that all the processes of hat manufacture from the raw fur-bearing skin to the finished product are carried on in this single plant. Philadelphia makes more hats than any other city in the United States.

Curtis Publishing Company. This plant, the home of the *Saturday Evening Post*, *The Ladies' Home Journal*, and *The Country Gentleman* occupies a whole city block, and millions of copies of its publications are turned out weekly. Of special interest is the new Curtis "four-and-four" precision color process by which four colors can be printed on both sides of a fast-moving sheet of paper, requiring no time interval for drying the different colors.

Burlington Generating Station of the Public Service Electric and Gas Company of New Jersey. Here may be seen the recently installed 100,000-kw cross-compound turbogenerator designed for 1,250 pounds, 950 degrees Fahrenheit total temperature. The duplicate generators for the high-pressure and low-pressure elements are both hydrogen cooled and rated 50,000 kilowatts, 3,600 rpm. Two boilers having a capacity of 550,000 pounds per hour generate steam at 1,350 pounds pressure, 950 degrees Fahrenheit total temperature, to supply this unit. The boilers are equipped to burn pulverized coal or fuel oil.

I.T.E. Circuit Breaker Company. Testing of circuit breakers using a new 32,000-kva 13,200-volt generator will be demonstrated. Visitors will also see air-blast breakers for 15,000 volts, 3,000 amperes, with interrupting capacity of 2,500,000 kva, low-voltage air circuit breakers, metal-clad switchgear for central station and industrial applications, silver-plating equipment for plating bus bars, and in the process of manufacture their line of low-voltage air breakers 15 to 50,000 amperes.

The Atlantic Refining Company Turbine Electric Tanker. An opportunity will be given to inspect one of the new tankers of the "J. W. Van Dyke" class. These tankers of 1,800 tons dead-weight are designed for an average sea speed of 13 1/4 knots and equipped with a variable speed of 4,500-kw main turbine generator and two 350-kw auxiliary turbine generator units. The main turbine is built for 600 pounds gauge steam pressure, 825 degrees Fahrenheit, and 28.5 inches vacuum. The generator is rated at 4,500 kw, 60 cycles, 2,300 volts, 3,600 rpm, and is coupled to the propeller shaft through a 500-horsepower 2,300-volt three-phase 90-rpm synchronous motor. The auxiliaries, except the feed pumps, are electrically driven. All motors except the main motor are totally encased and the switchgear and control are of the latest dead-front steel encased type.

Edward G. Budd Manufacturing Company. A pioneer in the development of steel automobile wheels and bodies, Budd also developed shot-welding for stainless steel and streamlined trains. Opportunity will be given to see the railroad car shop and automobile bodies in the making.

University of Pennsylvania. The laboratories of the Moore School of Electrical Engineering will be open for inspection. A special demonstration of the differential analyzer will be made. Opportunity will also be given to inspect the X-ray research laboratory and the atom smasher of the physics department will be demonstrated. The electrical research equipment of the Eldredge Reeves Johnson Foundation for medical physics will also be open for inspection.

Westinghouse Electric and Manufacturing Company plant at South Philadelphia, Pa.

The Institute Budget for the Year 1940–41

INFORMATION regarding the financial operations of the Institute is now given to the membership each year on two occasions, first with the publication of the annual report of the Institute board of directors for the fiscal year which ends April 30, and next with the adoption of a budget of income and expenditures for the appropriation year which begins October 1. The July 1940 issue of ELECTRICAL ENGINEERING, news section, pages 290–303, carries the complete report of the board of directors for the fiscal year which ended April 30, 1940, in which appears a detailed account of all activities of the organization together with financial statements for the corresponding period.

Accordingly, the budget of income and expenses for the year beginning October 1, 1940, which was adopted by the board of directors at its meeting held on October 25, is now presented in the form of a tabulation with only brief comments regarding those items which deserve special mention. For comparative purposes the tabulation includes a statement of the amounts actually received or expended during the budget year which ended September 30, 1940.

With respect to the estimate of the income to be received by the Institute during the coming year, the finance committee has again endeavored to make allowance for the probable loss of revenue from dues and from nonmember subscriptions to ELECTRICAL ENGINEERING received from abroad, which may result from conditions in those countries now affected by the war. It is estimated that the loss from these sources will be from $4,000 to $5,000 more than in the last budget year.

Upon review of the budget of appropriations it will be noted that practically all activities are being afforded financial support to the same extent as last year, and that in some cases an increased appropriation has been provided to allow for a further expansion of Institute activities.

It will also be noted that a transfer from surplus of $9,500 is to be made, to be added to the estimated receipts for the year. This is to take care of two special nonrecurring items of expense for publications. Thirty-two hundred dollars of this sum is to cover the expense of publishing in the 1940 TRANSACTIONS text matter which was presented in 1939 and therefore is more properly chargeable to the operations of that year. Sixty-three hundred dollars is to cover the effect of a change in publication policy adopted by the board last June, which will advance into the current budget year the publication of the first half of the 1941 SUPPLEMENT TO ELECTRICAL ENGINEERING—TRANSACTIONS SECTION. Under the former publication policy this expenditure would have been deferred until the 1941–42 budget year.

Increased appropriation for advance pamphlet copies is made to take care of an enlarged program of technical papers to be presented at national conventions and District meetings. The appropriation for Institute meetings provides for three national conventions and four District meetings, two more than last year.

The financial requirements for Institute Sections and Branches, for standing and technical committees, and for the various other activities shown in the tabulation have all been determined after careful study of the needs as estimated by the committees involved. The board of directors endeavors to adopt each year a budget which will make possible proper relative emphasis on the different phases of Institute activities and which limits the annual expenditures as far as possible to the amount of anticipated income for the corresponding period.

This year it is believed particularly important to have a small amount unappropriated, held for contingencies and probable additional items. The budget includes as yet no appropriation for depreciation; the appropriation for pension reserve is probably not fully adequate; it is a year in which cost levels may rise more than provided for in the budget items; and there are other matters which may call for expenditure by the Institute. Accordingly, the budget includes an "unappropriated" item of $7,910.

The success of all work planned for in the budget largely depends upon the prompt collection of membership dues, from which source over two-thirds of the total revenue of the Institute is received. It is gratifying to know that this situation is realized by the membership, as evidenced by the fact that the number of members in good standing at the beginning of the present fiscal year compares very favorably with the statistics of earlier years.

Institute Income and Expenses for Year Ending September 30, 1940, and Budget for Year Ending September 30, 1941

	Actual Income and Expenses, Year Ending 9-30-40	Budget for Year Ending 9-30-41
Income		
Dues	$205,282.38	$210,000.00
Students' fees	13,013.00	13,500.00
Entrance & transfer fees	7,880.95	8,000.00
Advertising	35,155.56	40,000.00
ELEC. ENGG.—nonmem. subscriptions.	12,939.44	10,500.00
TRANS. subscriptions.	7,002.70	7,000.00
Miscellaneous sales	14,973.10	16,800.00
Interest on securities	6,613.57	6,000.00
	302,860.70	311,800.00
Transfer from surplus		9,500.00
Total	$302,860.70	$321,300.00
Expenses		
Publications:		
Text matter (ELEC. ENGG. & TRANS.)	$ 74,126.67	$ 84,310.00
TRANS. SUPPLEMENT	322.88	1,425.00
Preprints	7,336.66	9,150.00
Advertising section—ELEC. ENGG.	17,230.72	20,100.00
Year Book	6,494.51	6,750.00
Miscellaneous expense	1,495.61	1,500.00
Institute meetings	12,842.60	14,200.00
Institute Sections:		
Appropriations	24,117.57	26,000.00
Other expenses	5,952.04	6,250.00
Institute Branches:		
Meetings expenses	1,180.68	1,200.00
Other expenses	2,577.99	2,850.00
Committees:		
Code of prin. prof. conduct		50.00
Edison Medal	176.86	160.00
Finance	600.00	750.00
Headquarters	61.20	100.00
Lamme Medal	181.30	210.00
Legislation		50.00
Membership	8,081.73	8,825.00
Standards	7,824.54	8,800.00
Technical committees	309.38	500.00
Traveling Expenses:		
Geo. Dist. exec. committees	2,459.40	3,000.00
Section delegates to summer conv.	6,829.73	5,900.00
Counselor delegates to summer conv.	1,145.74	1,000.00
Dist. secys. to summer conv.	927.28	800.00
District Student conferences	8,272.52	8,200.00
President's appropriation	865.50	1,500.00
Vice-presidents	855.13	1,000.00
Board of directors	6,040.02	7,250.00
National nominating committee	953.88	1,000.00
AIEE representatives		100.00
Administration:		
Headquarters' salaries	36,055.75	37,375.00
Postage	3,702.02	4,000.00
Stationery & printing	3,197.74	3,500.00
Office equipment	512.95	500.00
Trav. expense, bank charges, insurance, misc. supplies & services	4,254.68	4,500.00
Paper prizes	541.41	600.00
Joint activities:		
American Engineering Council	8,316.66	2,075.00
Amer. Co-ord. Com. Corrosion		25.00
American Standards Association	1,500.00	1,500.00
ECPD	850.00	850.00
Engg. Foundation research projects:		
Impregnated paper insulation	250.00	250.00
Insulating Oils & cable saturants	250.00	250.00
Welding	250.00	250.00
Engg. Soc. Personnel Service, Inc.	1,107.24	1,100.00
Engg. Soc. Library	9,899.90	10,075.00
Hoover Medal	175.55	
John Fritz Medal	50.00	50.00
N.F.P.A. Dues	60.00	60.00
United Engg. Trustees building assessment	10,984.81	11,000.00
U. S. Natl. Com. I.C.I.	300.00	300.00
Miscellaneous printing, etc.		5,150.00
Authors' reprints	3,184.02	
Reprints of standards	1,576.08	
Miscellaneous	1,187.05	
Other expenses:		
Membership badges	1,894.56	1,800.00
Legal services	250.00	250.00
Pension Fund Reserve	5,000.00	5,000.00
Text paper & env. in storage	554.84	
Depreciation Reserve Fund	233.87	
Unappropriated:		
Reserved for contingencies and additional items		7,910.00
Total	$295,311.27	$321,300.00

AIEE Board of Directors Meets

The regular meeting of the AIEE board of directors was held at Institute headquarters, New York, N. Y., on October 25, 1940.

Upon request of the committee on electrochemistry and electrometallurgy, authorization was given for a joint session with the American Society of Metals during the 1941 winter convention. Also, a joint technical conference of the committee on production and application of light with the Illuminating Engineering Society during the winter convention was authorized.

The board accepted an invitation of the local Sections and Districts concerned to hold the 1941 Pacific Coast convention at Yellowstone National Park, August 27–29. A joint conference on Student activities of Districts 8 and 9 and the University of British Columbia Branch, during this convention, was authorized.

Requests for approval of dates for three previously authorized District meetings during 1941 were considered. It was the consensus of the board that the District 7 meeting in St. Louis should be held in the fall; the dates April 30 to May 2 were approved for the District 1 meeting to be held in Rochester, N. Y.; and selection of the dates for the District 5 meeting in Fort Wayne, Ind., was delegated to the president, the vice-president of District 5, and the chairman of the committee on planning and coordination.

It was reported that, in accordance with action of the board of directors on August 2, the executive committee, in September, notified American Engineering Council of the intention of the AIEE to withdraw from Council on December 31, 1940; and the board confirmed this action.

The board authorized the usual contribution of $850 to the Engineers' Council for Professional Development for the year 1940–1941, and authorized a contribution of $25 toward the expenses involved in the work of the American Co-ordinating Committee on Corrosion, in which the Institute is participating.

A resolution in memory of Past President Louis A. Ferguson, who died on August 25, 1940, was adopted (see this page).

A new Student badge, in the form of a key charm, was authorized, to be sold at a price of $1.25.

Announcement was made that, due to the consolidation of Armor Institute of Technology and Lewis Institute, in Chicago, the Student Branches of the AIEE at these institutions had been merged into one Branch, to be known as the Illinois Institute of Technology Branch.

Upon recommendation of the standards committee, the board approved a revision of American standard for abbreviations for scientific and engineering terms—Z10, which had been prepared by a sectional committee of the American Standards Association.

Amendments to the rules governing the awards of national and District prizes of the Institute, recommended by the committee on award of Institute prizes, were adopted to:

1. Empower a District Executive committee to fix the dates of closure and award for the Branch paper and graduate student paper prizes in the district.

2. Provide a separate basis of grading papers for prize awards to student papers.

Authorization was given for the printing of a new edition of the pamphlet, "National and District Prizes," to include all revisions to date.

The board authorized the special committee on radio talks on electrical engineering subjects to arrange for a series of five radio talks along the lines suggested by the committee, beginning with one in connection with the 1941 winter convention and including phonograph records of the talks for use at local broadcasting stations throughout the country. The sum of $300 was appropriated for the purpose.

A budget for the appropriation year of the Institute beginning October 1, 1940, amounting to $321,300.00, was adopted as recommended by the finance committee.

The chairman of the committee on planning and co-ordination presented recommendations for modifications of proposals "E" and "F" of the publication committee for revisions of the publication policy of the Institute, which were adopted by the board of directors on June 27, 1940, and published in the August issue of ELECTRICAL ENGINEERING, page 332. A literal interpretation of these proposals had produced difficulties in connection with the necessary observance of budget limitations. The board approved these modifications, as an emergency action, as follows:

PROPOSAL E (placing a page limit, of six pages in type, on technical program papers to appear in the TRANSACTIONS section of ELECTRICAL ENGINEERING): In a sentence in the next to the last paragraph of the explanation of the objects of this proposal, the phrase "rather to assure publication" was changed to read "rather to give priority to publication".

PROPOSAL F: Changed to read:

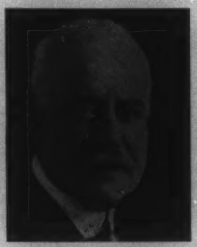
PROPOSAL F: Remove in so far as practicable restrictions set by the publication budget on the number of papers which may be approved by the technical program committee.

Under this plan the publication committee and technical program committee will recommend the following to the finance committee:

a. The number of pages of advance pamphlet copies of authors' manuscripts for which provision should be made in the budget.

b. The number of pages in TRANSACTIONS for which provision should be made in the budget.

In Memoriam



LOUIS A. FERGUSON

IN the death of Louis A. Ferguson, on August 25, 1940, at the age of 73, the Institute suffered the loss of its 21st president and one of the leading pioneers in electric power generation and distribution.

After his graduation from the Massachusetts Institute of Technology, in 1888, with the degree of bachelor of science, he was employed by the Chicago Edison Company as an engineer in the underground distribution department. He made rapid progress, serving as chief electrical engineer, 1889–1897, and in addition assuming charge of the contract department in 1893. In 1897, he was appointed general superintendent of both the Chicago Edison and the Commonwealth Electric Companies, and in 1902 he became second vice-president of both companies. The two companies were combined in 1907, and he continued as second vice-president of the Commonwealth Edison Company. He was a vice-president of that company from 1914 until his retirement on December 31, 1935.

Mr. Ferguson received national recognition for his contributions to power-system design, construction, and operation, and also for his leadership in the development of rate schedules for electric service.

He joined the Institute as an Associate in 1901, and was transferred to the grade of Member in 1904, and to the grade of Fellow in 1912. He served as manager 1904–07, vice-president 1907–08, and president 1908–1909.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its keen regret at the death of Mr. Ferguson and its appreciation of his many contributions to the development of Institute activities, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to the members of Mr. Ferguson's family.

—AIEE Board of Directors, October 25, 1940

Future AIEE Meetings

Winter Convention
Philadelphia, Pa., January 27–31, 1941

Great Lakes District Meeting
Fort Wayne, Ind., April 1941

North Eastern District Meeting
Rochester, N. Y., April 30–May 2, 1941

Summer Convention
Toronto, Can., June 16–20, 1941

Pacific Coast Convention
Yellowstone National Park, August 27–29, 1941

(This is expected to be a smaller amount of material than that published in advance pamphlet form.)

The technical program committee procedure would then be as follows:

1. Review and approve or disapprove all technical papers submitted for program consideration. The total number of papers that may be approved will be limited only by the advance pamphlet budget.
2. Same as previous item 2.
3. Same as previous item 3.
4. Advise the publication committee which of the papers approved by the technical program committee are recommended by the technical program committee for publication in TRANSACTIONS, the total of these not to exceed the TRANSACTIONS' budget limit. Each author is to be advised when notified of the acceptance of his paper whether or not his paper will be recommended for publication in TRANSACTIONS.

The procedure in the publication committee would not differ in any general way from the present one but the proportion of the total number of technical program committee approved papers appearing in ELECTRICAL ENGINEERING would vary, depending upon the available budget. However, with proposed changes C, D, and E above, in effect the number of such papers appearing in ELECTRICAL ENGINEERING would be increased without any increase in the publication budget. Specifically the publication committee procedure would be:

5. Publish in TRANSACTIONS all technical papers and discussions thereof which have been approved and recommended for publication by the technical program committee.
6. Previous item 5 with no change.
7. Previous item 6 with no change.
8. Previous item 7 with no change.

The following board members were selected to serve on the national nominating committee:

C. R. Beardsley, M. S. Coover, Everett S. Lee, L. R. Mapes, and H. S. Osborne

Alternates: T. F. Barton, F. Malcolm Farmer, D. C. Prince, Mark Eldredge

R. T. Henry was appointed a representative of the Institute on the Standards Council of the American Standards Association for the three-year term beginning January 1, 1941, and H. E. Farrer, H. H. Henline, and E. B. Paxton were reappointed alternates for the year 1941.

C. R. Beardsley was appointed a representative of the Institute on the board of trustees of United Engineering Trustees, Inc., for the four-year term beginning in October 1940, to fill the vacancy caused by the death of H. R. Woodrow.

Other actions by the board included the following:

Minutes of the meeting of the board of directors held on August 2, 1940, were approved.

The following actions of the executive committee as of September 16, 1940, were reported and confirmed: 17 applicants transferred and 10 elected to the grade of Member; 34 applicants elected to the grade of Associate; 17 Students enrolled.

Reports of meetings of the board of examiners held on September 12 and October 17, 1940, were presented and approved. Upon recommendation of the board of examiners, the following actions were taken: 5 applicants elected to the grade of Member; 33 applicants elected to the grade of Associate; 559 Students enrolled.

Monthly expenditures were reported by the chairman of the finance committee and approved by the board, as follows: $18,587.43 in August, $20,428.29 in September, and $30,724.24 in October.

Those present were:

President—R. W. Sorensen, Pasadena, Calif.

Past Presidents—F. Malcolm Farmer and John C. Parker, New York, N. Y.

Vice-Presidents—J. W. Barker, New York, N. Y.; J. L. Hamilton, St. Louis, Mo.; K. L. Hansen, Milwaukee, Wis.; H. W. Hitchcock, Los Angeles, Calif.; Everett S. Lee, Schenectady, N. Y.; Fred R. Maxwell, Jr., University, Ala.; C. T. Sinclair, Pittsburgh, Pa.; A. LeRoy Taylor, Salt Lake City, Utah; J. M. Thomson, Toronto, Ont.; A. L. Turner, Omaha, Nebr.

Directors—T. F. Barton, C. R. Beardsley, H. S. Osborne, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; R. E. Hellmund, East Pittsburgh, Pa.; F. H. Lane, L. R. Mapes, Chicago, Ill.; D. C. Prince, Schenectady, N. Y.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter and *National Secretary*—H. H. Henline, New York, N. Y.

AIEE Prize Rules Changed for National and District Papers

Provision in the Institute's 1940–41 budget has been made for cash awards to accompany the national and District prizes for initial and Branch papers to be awarded during the current year, as indicated below.

All technical papers presented before the Institute are eligible under the AIEE paper prize regulations for competitive consideration for one or more of the established prizes, regardless of whether presented before a Branch meeting, a Section meeting, a District meeting, or a national convention, the several classes of prizes providing for equitable competition.

National prizes that may be awarded annually, and those to be accompanied by cash awards during the current year, are as follows:

1. Best paper prizes (certificates):
   Engineering practice
   Theory and research
   Public relations and education
2. Prize for initial paper ($100 and certificate)
3. Prize for Branch paper ($100 and certificate)

District prizes that may be awarded annually in each of the geographical Districts of the Institute, together with the cash awards provided for the current year, are:

1. Prize for best paper (certificate)
2. Prize for initial paper ($25 and certificate)
3. Prize for Branch paper ($25 and certificate)
4. Prize for graduate student paper (certificate)

PERIODS OF COMPETITIONS

The national "best paper prizes" and the national "initial paper prize" are awarded for papers presented during the calendar year, except best paper prize in the class of public relations and education. In this class the award is for a paper presented subsequent to those considered at the time of the last previous award in this field and prior to the end of the calendar year. For the national "prize for Branch paper" only papers presented during the preceding academic (college) year, July 1 to June 30, inclusive, will be considered.

The District "prize for best paper" and the District "prize for initial paper" are awarded only for papers presented subsequent to the period covered by the last previous award in the class and prior to the end of the last calendar year. The District "prize for Branch paper" and the District "prize for graduate student paper" are awarded only for papers presented subsequent to the period covered by the last previous award in the class and prior to the end of the last academic (college) year, July 1 to June 30, inclusive.

TIME OF AWARDS

All of the national prizes and the District "prize for best paper" as well as the District "prize for initial paper" shall be awarded prior to May 1 of the succeeding year. The District "prize for Branch paper" and the District "prize for graduate student paper" will be awarded as determined by the District executive committee and announced to all Branches in the District.

HOW TO SUBMIT PAPERS

For the national prizes all papers approved by the technical program committee which were presented at the national conventions or District meetings will be considered for the best paper prizes and the initial paper prize without being formally offered for competition. All other papers which were presented at Section or Branch meetings must be submitted in triplicate with written communications to the national secretary on or before February 15 of the following year, stating when and where the papers were presented.

For the District "prize for best paper" and the District "prize for initial paper" papers shall be submitted at least in duplicate by authors or by officers of the Section, Branch, or District concerned to the District secretary on or before February 15. The District secretary will refer the papers either to the District executive committee or a committee appointed by the District executive committee authorized to make the awards. For the District "prize for Branch paper" and "prize for graduate student paper" papers shall be submitted at least in

A Good Deed

Mr. Institute Member:

A Boy Scout is expected to do one good deed each day, but we only ask you as an Institute member to do one good deed each year, viz., to suggest to your Section membership committee the name or names of men of your acquaintance who are eligible for membership but are not now affiliated with the Institute.

Or better still, if you wish to make it a real good deed, in addition to sending in their names, talk with them yourself and get them interested. This will pave the way for the membership committee contacts and improve the possibilities of their success.

C. C. Brill

Chairman, National Membership Committee

duplicate by authors or by officers of the Section, Branch, or District concerned to the District secretary in accordance with dates of closure and of award, as fixed by the District executive committee and announced to all Branches in the respective Districts.

The basis of evaluating all student papers has been changed to bring it more in conformity with the objectives of such papers. Those wishing further information may obtain a booklet entitled "National and District Prizes" from AIEE headquarters, 33 West 39th Street, New York, N. Y.

District • • • •

District 1 Executive Committee Meets at Pittsfield

With an attendance of Section and other representatives as noted in the following list, the executive committee of the Institute's North Eastern District met at Pittsfield, Mass., Friday, October 4, 1940:

R. G. Lorraine, secretary, North Eastern District
H. H. Henline, national secretary, AIEE
A. G. Conrad, secretary, Connecticut Section
G. L. Dawes, past vice-president
E. M. Hunter, chairman, Schenectady Section
T. T. Woodson, secretary, Schenectady Section
A. H. Magnusan, chairman, Worcester Section
V. Siegfried, national membership committee
Eric A. Walker, Student Branch counselor, Connecticut
W. I. Middleton, secretary-treasurer, Boston Section
O. E. Sawyer, secretary-treasurer, Providence Section
H. A. Baines, chairman, Providence Section
E. V. Deblieux, chairman, Pittsfield Section
W. K. Parks, secretary, Niagara Frontier Section
H. D. Griffith, chairman, Springfield Section
Isaiah Creaser, secretary, Springfield Section
W. F. Cotter, chairman, Rochester Section
H. H. Race, chairman, Schenectady Section
M. B. Scoville, secretary-treasurer, Pittsfield Section
M. G. Northrop, chairman, Ithaca Section
R. W. Adams, chairman, Boston Section
E. S. Lee, vice-president, AIEE

Actions taken by the committee include the following:

1. Approved the dual method of transferring to Fellow grade, as discussed at the annual conference of officers, delegates, and members held in connection with the 1940 summer convention at Swampscott, Mass., and reported on pages 335–6 of the August issue of ELECTRICAL ENGINEERING.

2. Approved Vice-President E. S. Lee's appointment of the following men to serve with him on the District co-ordinating committee: R. D. Lorraine of Schenectady, A. G. Conrad of New Haven, H. D. Griffith of Springfield, O. E. Sawyer of Providence, M. G. Northrop of Ithaca, and E. A. Gruppe of Syracuse.

3. Approved Vice-President Lee's appointment of W. F. Cotter of Rochester and C. E. Tuites of Rochester to serve with the members of the District co-ordinating committee as the general committee for the District meeting scheduled to be held in Rochester April 30–May 2, 1941.

4. Approved Vice-President Lee's appointment of D. S. Snell of Schenectady, W. I. Middleton of Cambridge, and W. K. Parks of Buffalo to act as judges for the District's initial and best-paper prize awards, and W. W. Cotner of Ithaca, R. C. Porter of Boston, and A. G. Conrad of New Haven to act as judges for Student Branch paper prize awards.

5. Voted financial support to the extent of some $300 for District student convention activities, and $30.00 for District prizes.

6. Adopted an assessment of $20.00 plus five cents per AIEE member for each Section in the North Eastern District, to defray the expenses of general District activities.

7. Elected Past-Vice-President C. L. Dawes to represent the North Eastern District on the national nominating committee.

Chairman E. A. Walker of the District's committee on student activities reported that the District's 17 student branches had a total membership of nearly 400 Enrolled Students, with a gross total attendance of 6,500 during the past school year at 141 branch meetings for which the programs included some 70 student talks; that there was a total attendance of about 150 at the Student District conference held at Rensselaer last Spring where 5 graduate and 16 undergraduate student papers were presented. Student branch counselors are planning to hold this year's student convention in connection with the District meeting scheduled for Rochester. AIEE national affairs of interest to the District and its Sections were discussed by Past-Chairman H. H. Race of the national sections committee, Vice-Chairman Victor Siegfried of the national membership committee, and National Secretary H. H. Henline.

District 2 Co-ordinating Committee

By action of the District 2 executive committee at its meeting held October 10, 1940, during the Middle Eastern District meeting at Cincinnati, Ohio, the following men were selected to serve as the co-ordinating committee for the Middle Eastern District in connection with the 1942 District meeting in Pittsburgh, Pa.:

F. S. Fiske, Maryland Section
W. R. Hough, Cleveland Section
M. B. Wyman, Pittsburgh Section
W. J. D. Geary, Lehigh Valley Section

Executive Committee of District 6 Meets at Denver

The executive committee of the North Central District held its annual meeting at the University Club, Denver, Colo., November 1, 1940, with the following Section and other representatives present:

A. L. Turner, vice-president
Nelson R. Love, vice-chairman, national membership committee
W. G. Rubel, chairman, Denver Section
John R. Walker, secretary, Denver Section
L. A. Bingham, chairman, Nebraska Section
John M. Gibb, secretary, Nebraska Section
H. F. Rice, chairman, District committee on student activities
I. M. Ellestad, District secretary

Actions taken by the executive committee included the following:

1. Nominated Arthur L. Jones (F'38) vice-president and district manager of the General Electric Company at Denver, for the office of AIEE vice-president from District 6 for the two-year term beginning August 1, 1941. Mr. Jones is past chairman of the Denver Section, 1927–28.

2. Appointed Albert S. Anderson past chairman of the Denver Section (1938–39) to represent District 6 at the forthcoming January meeting of the national nominating committee. Byron E. Cohn of Denver was selected as District alternate representative.

3. Took action recommending that each Section in District 6 consider making an appropriation of about $7.50 to provide a fund to be used for District prizes for student papers, awards to be made at the annual conference on student activities.

4. Appointed Chairman W. G. Rubel and Secretary J. R. Walker of the Denver Section and District Vice-Chairman Nelson R. Love of the national membership committee to constitute a committee of judges to consider the student papers that will be presented at the annual conference on student activities to be held at the University of Denver April 18–19, 1941.

5. Endorsed the invitation from the Denver Section to the Institute to hold the 1942 annual summer convention in Denver.

Other items of District business discussed included the matter of membership and the subject of rules governing the awards of District prizes for Student Branch papers.

Section • • • •

Milwaukee Section Forms Discussion Groups

Three technical discussion groups have been organized by the AIEE Milwaukee Section, with the objectives of providing forms for technical discussion and giving young engineers experience in presenting papers. The groups were formed after replies to a questionnaire showed great interest in the plan. Others will be added if sufficient demand appears.

The co-ordinating chairman of the project is C. J. Fechheimer and the three groups, which held their first meetings in November, are:

Group A, electrical machinery—S. H. Mortensen, chairman
Group B, power applications and controls—K. L. Hansen, chairman
Group C, electronics—Walter Richter, chairman

Each group expects to meet about four times a year. Only AIEE members or local members of the Section may participate, but any member may join more than one group.

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y., or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

Basic Sciences

41-4—Calculation of Initial Breakdown Voltages in Air; *D. W. Ver Planck (A'31). 20 cents by mail.* Although spark-over and corona starting voltages can be predetermined satisfactorily in cases for which empirical formulas or curves are available, a more generally applicable method is needed. An approach to such a method is through a modification of Townsend's theory, which, though possibly lacking in rigor, suffices in many cases for the accurate calculation of breakdown voltages. The present paper outlines the theory and shows that the initial breakdown voltage may be calculated using two quantities characteristic of the gas for cases where the field, if nonuniform, converges toward the cathode. Formulas ex-

pressing one of the characteristic quantities for air, the Townsend coefficient α, are assembled, and a formula for the second quantity is deduced from an analysis of published spark-over gradients for plane gaps. The method is applied to two cases and the results are shown to be in agreement with experiment.

41-6—A Five-Figure Table of the Bessel Function $I_n(x)$; *H. B. Dwight (F'26). 15 cents by mail.* The modified Bessel function of the first kind, $I_x(x)$, where x is a real quantity, is of widespread application, but it is of particular interest to electrical engineers, since the current and voltage for a traveling wave on an electric line can be expressed as a series of these functions. A table of these functions was published in the Report of the British Association for the Advancement of Science, 1889, and has been reprinted in "Bessel Functions" by Gray, Mathews, and MacRobert. While a large number of significant figures were given, the arguments were 0.2, 0.4, 0.6, etc. The interpolation, as used in engineering work, is somewhat easier and more according to a decimal system when arguments 0.1, 0.2, 0.3, etc., are used. Accordingly, additional values for a five-figure table have been computed, and the enlarged five-figure table is given in this paper.

41-9—D-C Breakdown Strength of Air and of Freon in a Uniform Field at High Pressures; *J. G. Trump (A'31), F. J. Safford (A'35), and R. W. Cloud (A'39). 15 cents by mail.* This paper extends d-c breakdown studies in air and in Freon 12 (dichlorodifluoromethane) at high pressures and in a uniform field to higher voltages than have been reported previously, and indicates reasons for the observed departures from Paschen's law and for the relatively high insulating strength of the Freon. D-c breakdown studies of air in a uniform field have been extended to 1,000 kv. D-c studies of Freon (CCl_2F_2) have been extended to over 350 kv and to 135 pounds per square inch absolute. The mechanisms which account for the higher insulating strength of such gaseous compounds as CCl_2F_2 are outlined and their possibilities and limitations in the insulation of high-voltage apparatus are briefly discussed.

Communication

41-8—Hollow Pipes of Relatively Small Dimensions; *W. L. Barrow (M'33), H. Schaevitz (A'40). 15 cents by mail.* The hollow-pipe type of conductor for ultra-high-frequency electromagnetic energy, although possessing several desirable features, has the disadvantage that its transverse dimensions are relatively large; namely, of magnitude comparable to the wave length. The object of this paper is to lessen this encumbrance by describing pipes that have transverse dimensions several times smaller than those of the simple forms previously proposed. Several cross-sectional shapes for hollow-pipe transmission lines are described that provide lower operating frequencies for given outside dimensions than do the simple shapes heretofore proposed. The theory for one such line, the "separate coaxial cable", is derived, and experiments are reported. Cavity resonators embodying these principles are also described.

Electrical Machinery

41-1—"Rotor-Bar Currents in Squirrel-Cage Induction Motors"; *J. S. Gault (M'30). 20 cents by mail.* The rotor of a squirrel-cage induction motor is an extremely simple and rugged piece of mechanism; and due largely to this simplicity, it resists accurate analysis of its behavior by ordinary testing technique. Its design has been perfected by cut-and-try methods, making assumptions with respect to rotor current to simplify the theory, but the actual current in the bars has remained a mystery. The purposes of this paper are: first, to present oscillograms of rotor-bar currents; second, to extend the theory of induction motors to include the computation of rotor-bar currents; and third, to show the effect of the rotor-current harmonics upon the efficiency of the motor.

41-2—Analysis of Short-Circuit Oscillograms; *W. W. Kuyper (A'34). 15 cents by mail.* The analysis of short-circuit oscillograms to obtain synchronous-machine reactances is usually made by means of the equations developed from symmetrical-component theories. These equations have been employed by previous writers on the subject and have been incorporated in published standards. Because symmetrical-component methods usually start from the assumption of sinusoidal currents of single frequency in the armature, and because it is known that short-circuit currents depart appreciably from the simple sinusoidal form, it is desirable to know the effect of removing the assumption of sinusoidal currents on the equations used in the analysis of short-circuit oscillograms. Methods of analyzing the oscillograms of short-circuit currents of synchronous machines, in accordance with the two-reaction theory, are presented in this paper. Differences between the results found here and the more generally accepted equations, based on symmetrical components, are pointed out.

Power Transmission and Distribution

41-5—Impulse and 60-Cycle Characteristics of Driven Grounds; *P. L. Bellaschi (F'40). 20 cents by mail.* Driven grounds are important in electric power transmission and distribution. In fact, they comprise one of the essential elements in the art of lightning protection. Yet, to this day, the value of protection derived from grounds under actual operating conditions of lightning discharge is difficult to state in full quantitative measure. And the reason for this situation lies partly in the lack of fundamental knowledge of the impulse characteristics of driven grounds. In part, the difficulty also is due to the complex factors that inherently make up driven grounds and ground systems. This paper presents an investigation supplying test data on the impulse and 60-cycle characteristics of common rods driven in natural soil (largely clay composition). It sums up and analyzes the results in the characteristic curve of the ratio of impulse to 60-cycle resistance for impulse currents that represent conditions ranging from a traveling surge to direct strokes of lightning. The basic reasons for the performance of grounds under impulse currents are pointed out in so far as the experimental data and observations permit. From this investigation the desirability of establishing the characteristic for other typical soils and for other common types of grounds (electrodes) is apparent.

Instruments and Measurements

41-3—Automatic Printing Ammeter; *T. G. LeClair (F'40). 20 cents by mail.* A new meter has been developed which will automatically read and record in numerals, at predetermined time intervals, the ampere loading on 50 different electric circuits. This meter also adds meter readings on groups of circuits and prints these totals in columns beside the meter readings. The paper outlines briefly the reasons for developing such a device. The paper also describes, with the aid of schematic diagrams, the process by which the meter obtains and prints all the meter readings on a single "log sheet". The following are incidental benefits derived from the use of the meter: greater accuracy, greater legibility, duplicate records, and uniform timing of readings.

Personal • • •

E. E. Minor, Jr. (A'35) research and development engineer, the Glenn L. Martin Company, Baltimore, Md., has been appointed chairman of the Institute's newly formed committee on air transportation. He was born at Baltimore February 18, 1907, and received the degrees of bachelor of engineering, 1930, and doctor of engineering, 1934, from Johns Hopkins University. During part of 1934 he was employed by the Pennsylvania Railroad at Washington, D. C., as assistant electrical engineer on high-voltage cable installation. While doing graduate work at Johns Hopkins, he was engaged in research on space charge effects in liquid dielectrics, continuing that work until 1935. Following a year and a half of work on job analysis in the United States Department of Labor, he became staff electrical engineer for the Glenn L. Martin Company, later becoming electrical engineer and research and development engineer. During this period he has been responsible

E. E. MINOR, JR.

for the progress and development of electrical engineering as applied to large aircraft. He has also carried on consulting work in electrical engineering. He is also a member of Sigma Xi and of the Institute of Aeronautical Sciences.

O. P. Cleaver (A'36) lighting engineer, Westinghouse Lamp Division, Bloomfield, N. J., and **F. A. Hansen** (M'31) managing director, Western Institute of Light and Vision, Los Angeles, Calif., have been elected regional vice-presidents of the Illuminating Engineering Society for 1940–41, in accordance with the society's recent establishment of eight geographical divisions, called "regions." Mr. Cleaver, who will serve as vice-president of region B, comprising the New York and New England sections of the IES, was born January 8, 1907, at Rowlettes, Ky., and received the degrees of bachelor of science in electrical engineering from Georgia Institute of Technology in 1928 and master of science in electrical engineering from Yale University in 1930. Since 1930 he has been with the Westinghouse Lamp Division; from 1930 to 1935 as district engineer at Chicago, Ill. Since 1935 he has been in charge of the illumination section, commercial engineering department. He is a member of the Institute's committee on production and application of light. Mr. Hansen will serve as vice-president of region "H," covering the Pacific Coast area. He was born December 29, 1898, at Mineral, Idaho, and studied electrical engineering at the Bliss Electrical School. For some years he was Pacific Coast representative of the Hollophane Company, Inc., and since 1935 has been managing director of the Western Institute of Light and Vision. Both men have been active in committee and section work in the IES.

L. R. Ludwig (A'28) formerly manager of the protective devices engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been made manager of the two newly combined divisions of circuit breaker and protective devices engineering. A native (1904) of Kansas City, Mo., he received the degree of bachelor of science in electrical engineering from the University of Illinois in 1925, and entered the student course at Westinghouse the same year. He has been with the company continuously except for the year 1929–30, which he spent in graduate study at the University of Berlin as recipient of the first Lamme Memorial scholarship. In 1931 he entered the research division of railroad motor engineering, and since 1935 has been in the switchgear division. He was co-author of the AIEE national prize best paper in theory and research in 1933, and received honorable mention in the same award in 1936.

R. D. Bennett (F'35) professor of electrical measurements, Massachusetts Institute of Technology, Cambridge, has been appointed lieutenant-commander in the United States Naval Reserve, with headquarters at the Naval Ordnance Laboratory, Washington, D. C. Born June 30, 1900, at Williamson, N. Y., he received the degrees of bachelor of science (1921) and master of science (1923) in electrical engineering from Union College, and that of doctor of philosophy from the University of Chicago in 1925. He taught in mathematics (1921–23) and physics (1925–26) at Union College, Schenectady, N. Y., and was National Research fellow in physics at Princeton University, Princeton, N. J., 1926–27, and at California Institute of Technology, 1927–28; and research associate at the University of Chicago, Chicago, Ill., 1928–31. He went to MIT as associate professor of electrical measurements in 1931, later becoming professor.

F. E. Terman (A'23, M'34) executive head, electrical engineering department, Stanford University, Stanford University, Calif., has been elected president of the Institute of Radio Engineers for the year 1941. He is at present a vice-president of the society. Born June 10, 1900 at English, Ind., he received the degrees of bachelor of arts (1920) and electrical engineer (1922) from Stanford University and that of doctor of science from Massachusetts Institute of Technology in 1924. He entered the electrical engineering department at Stanford University in 1925, becoming assistant professor in 1927, associate professor in 1930, and later professor. He is the author of books and articles on communications, holds a number of patents, and has also carried on consulting work.

E. O. Shreve (A'06) vice-president in charge of apparatus sales, General Electric Company, Schenectady, N. Y., has been elected president of the National Electrical Manufacturers' Association for 1940–41. A native (1881) of Mapleton, Iowa, he received the degree of bachelor of science in electrical engineering in 1904. He went with General Electric as a student engineer the same year and has been with the company ever since. He was sent to the Pacific Coast in 1906 as supply salesman, and in 1917 became manager of the San Francisco office. He was made manager of the industrial department at Schenectady in 1926, assistant vice-president in 1929, and vice-president in 1934.

H. B. Burr (A'21, M'40) has retired as plant engineer, Wisconsin Telephone Company, Milwaukee. Born July 26, 1875, at Milwaukee, he studied engineering at the University of California. Before entering the employ of the Wisconsin Telephone Company in 1905, he was employed as a draftsman by the Milwaukee Engineering Company, the Bucyrus Manufacturing Company, and the Kearney and Trecker Company, all of Milwaukee, and from 1903 to 1905 as assistant to superintendent of construction, Allis-Chalmers Company, Milwaukee. He went with the Wisconsin Telephone Company as inspector, became assistant aerial construction engineer in 1907, and in 1921 was made plant engineer.

L. B. Bender (A'20, M'27) has joined the Westinghouse Electric and Manufacturing Company as engineer for the research products department, with headquarters at Baltimore, Md., having retired at his own request as colonel in the Signal Corps, United States Army. He has been a commissioned officer in the Army since 1909, and has been closely identified with research work in the Signal Corps, as he has served as director of each of the Signal Corps laboratories, and as chief of the research and development division of the Chief Signal Officer's office in Washington, D. C.

F. E. Bell (M'35) has been appointed construction engineer for the new steam generating plant which is being built by the Tennessee Valley Authority near Watts Bar Dam, Tenn. He has been associated with TVA since 1934, serving as assistant construction engineer of the Joe Wheeler and Guntersville Dams in Alabama. Previously he had been with United Engineer and Constructors, Inc., Philadelphia, Pa.; United Gas Improvement Contracting Company, Philadelphia; and Stone and Webster, Inc., Boston, Mass.

E. C. Stone (M'19, F'31) vice-president and general manager, Duquesne Light Company, Pittsburgh, Pa., has been elected president of the Pennsylvania Electric Association for 1940–41. **H. M. Rankin** (A'20, M'22) superintendent of power supply, Metropolitan Edison Company, Reading, Pa., was elected a member of the executive committee of the Association, and **H. S. Fitch** (A'18) general superintendent of substations, West Penn Power Company, Pittsburgh, Pa., was elected vice-chairman of the Association's engineering section.

A. D. Hinckley (A'27, M'38) assistant to the dean of the faculty of engineering and instructor in electrical engineering at Columbia University, New York, has been granted a temporary leave of absence to serve as senior consultant in engineering education in the Office of Education of the Department of the Interior, Washington, D. C.

K. A. Hawley (A'09, F'35) formerly chief engineer, Victor Insulators, Inc., Victor, N. Y., has been appointed engineer of new products, Electric Power Equipment Corporation, Philadelphia, Pa. He had been with Victor Insulators since 1935, and previously was chief engineer of the Locke Insulator Corporation, Baltimore, Md.

W. V. Kahler (M'39) chief engineer, Illinois Bell Telephone Company, Chicago, Ill., has been given leave of absence to report to W. H. Harrison (A'20, F'31) vice-president and chief engineer of the American Telephone and Telegraph Company, now with the National Defense Advisory Commission, Washington, D. C.

E. E. Wyland (A'29, M'39) formerly general plant supervisor, Mountain States Telephone and Telegraph Company, Denver, Colo., has been appointed Colorado plant superintendent. He has been with the company since 1924 and was appointed general plant supervisor in 1939.

A. M. Musgrove (A'30, M'37) formerly assistant engineer, transmission and distribution, Public Service Electric and Gas Company, Newark, N. J., has been assigned to active duty with the United States Army as engineer officer for the Third Military Area, with headquarters at Newark.

D. J. LaMothe (A'35) has been appointed an instructor in electrical engineering at Michigan College of Mining and Technology, Houghton. A graduate of that institution (1934) he has been engaged in research at the American Television Institute, Chicago, Ill.

W. M. Hanna (A'26) formerly employed in the engineering division, central station department, General Electric Company, Schenectady, N. Y., is now assistant to the electrical engineer, Consolidated Gas, Electric Light, and Power Company, Baltimore, Md.

E. A. Walker (A'34) formerly chairman of the department of electrical engineering, Tufts College, Medford, Mass., has been appointed associate professor of electrical engineering at the University of Connecticut, Storrs.

F. J. Amador (A'36) formerly assistant professor of electrical engineering, New Mexico State College, State College, is now an assistant engineer for the United States Government at the Panama Canal, engaged on the design of the third set of locks.

G. E. Hulse (M'22) chief engineer, The Safety Car Heating and Lighting Company, New Haven, Conn., has been elected a manager of The American Society of Mechanical Engineers to serve on the council of that society for a three-year term.

J. A. Caparo (M'18, F'32) professor of electrical engineering, University of Notre Dame, Notre Dame, Ind., has received the Notre Dame Alumni Association award, granted annually to a member of the faculty in recognition of outstanding work.

R. W. Wilbraham (M'21) chief electrical engineer, United Engineers and Constructors, Inc., Philadelphia, Pa., has been appointed chairman of the committee on electrical equipment of the Edison Electric Institute for the year 1940–41.

S. P. MacFadden (A'19, M'30) has been elected to serve the Northwest Electric Light and Power Association as vice-president for 1940–41. He is vice-president in charge of operations for Puget Sound Power and Light Company, Seattle, Wash.

O. A. Becklund (A'38) formerly instructor in electrical engineering, Case School of Applied Science, Cleveland, Ohio, is now a member of the department of electrical engineering at the University of Minnesota, Minneapolis.

L. D. Colvin (A'39) has been granted a year's leave of absence from his position as junior engineer, Pacific Gas and Electric Company, San Francisco, Calif., to serve as first lieutenant in the Signal Corps, United States Army, stationed at San Francisco.

L. P. Winsor (A'40) formerly assistant at the Graduate School of Engineering, Harvard University, Cambridge, Mass., has now joined the staff of the Case School of Applied Science, Cleveland, Ohio.

Meirion Davies (A'37) managing director, Langley Manufacturing Company, Vancouver, B. C., Canada, has been elected chairman of the Granville Island branch of the Canadian Manufacturers' Association.

J. O. Binney (M'35) formerly electrical engineer, Metropolitan Water District of Southern California, Los Angeles, is now employed in the chief engineer's office of the Southern California Edison Company, Los Angeles.

S. E. Gates (A'36) manager, Los Angeles (Calif.) office, General Electric Company, has been elected a vice-president of the Pacific Coast Electrical Association for the coming year.

R. P. Long (A'34) formerly general plant employment supervisor, eastern district, Bell Telephone Company of Pennsylvania, Philadelphia, has been appointed general plant manager.

R. W. King (M'35) assistant to the president, Bell Telephone Laboratories, has been transferred to the position of assistant vice-president, American Telephone and Telegraph Company.

C. A. Collier (M'23) vice-president in charge of sales, Georgia Power Company, Atlanta, Ga., has been appointed Georgia representative on the southern industrial mobilization committee for national defense.

J. H. Herron (M'35) president, the James H. Herron Company, Cleveland, Ohio, has been made an honorary member of the Cleveland Engineering Society.

L. S. White (A'25) formerly district manager, Portland General Electric Company, Gresham, Ore., has been transferred to the Portland office of the company.

Obituary • • •

Charles Hesterman Merz (A'95, M'10, F'13) consulting electrical engineer, senior partner, Merz and McLellan, London, England, died during October 1940 when his London home was destroyed by a bomb. He was born at Gateshead-on-Tyne, England, October 5, 1874, and received his technical education at Armstrong College, Newcastle-on-Tyne, as a student of the University of Durham. He was awarded the honorary degree of doctor of science by the University of Durham in 1932. He was an apprentice of the Newcastle-on-Tyne Electric Supply Company; pupil engineer for Robey and Company, Lincoln; and resident engineer for Croydon Corporation Electricity Works (1897) and for Cork Electric Tramways and Lighting Company, Ltd. (1898–99) before devoting himself to consulting practice. He was especially concerned with power supply and designed and carried out electric power and traction work in England, India, Australia, Africa, the United States, and South America. He was a member of the Home Office committee on electricity in mines, 1910; chairman, electric power supply subcommittee of the coal conservation committee of the Ministry of Reconstruction, 1917; member of the Board of Trade committee on electric power supply, 1917; and director of experiments and research for the British Admiralty, 1918. He received the Faraday Medal of the Institution of Electrical Engineers of Great Britain in 1931, and was a past vice-president of that organization. He also was a member of the Institution of Civil Engineers, Great Britain, of the British Engineering Standards Committee, the Electrochemical Society (American), and the Franklin Institute.

John Renshaw Carson (A'19, F'33) research mathematician, Bell Telephone Laboratories, New York, N. Y., died October 31, 1940. He was born June 28, 1886, at Pittsburgh, Pa., and received the degrees of bachelor of science, 1907, electrical engineer, 1909, master of science, 1912, from Princeton University, and the honorary degree of doctor of science from Brooklyn Polytechnic Institute 1936. From 1907 to 1910 he was a student engineer with the General Electric Company, Schenectady, N. Y. He was employed in the research division of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., 1911–12, and as an instructor in physics and electrical engineering at Princeton University, Princeton, N. J., 1912–14. In 1914 he entered the engineering department of the American Telephone and Telegraph Company, New York, N. Y., and in 1917 was transferred to the department of development and research as engineer of transmission theory development. When that department was consolidated with the Bell Telephone Laboratories in 1934, he assumed the position of research mathematician in that organization. He received the Liebmann Memorial Prize of the Institute of Radio Engineers in 1924, and the Elliott Cresson Medal of the Franklin Institute in 1939, and was named a "modern pioneer" by the National Association of Manufacturers in 1940. He was also a member of the Institute of Radio Engineers, the American Mathematical Society, and Phi Beta Kappa. He was the author of books and technical papers and held a number of patents.

Eli Franklin Bush (A'08) attorney at law, Los Angeles, Calif., died September 6, 1940. He was born at Quaker, Mich., April 6, 1883, received the degree of bachelor of science from the University of Michigan in 1906, and also studied law at the University of Southern California. He entered the employ of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., in 1906, and the following year was transferred to the company's sales office at Philadelphia, Pa., as understudy salesman. From 1908 to 1915 he was salesman for the Philadelphia office, and for the next two years worked on application of motors to machine tools and various kinds of machinery. In 1917 he was put in charge of that work at East Pittsburgh. He went with the United States Bureau of Aircraft Production, procurement division, the following year, and later went to Los Angeles, Calif., where he studied law and was admitted to the bar in 1923. Since that time he had been engaged in general law practice in Los Angeles.

William Norman McAnge, Jr. (A'25, M'28) president and treasurer, Inter-Mountain Telephone Company, Bristol, Tenn., died August 30, 1940. He was born at Suffolk, Va., August 1, 1882, and received the degree of bachelor of science from Virginia Polytechnic Institute in 1902. He was chief

engineer of the Atlantic Coast Construction Company, Suffolk, Va., 1902–06; sales engineer, Electric Heating Manufacturing Company, Los Angeles, Calif., 1906–07; manager, Consolidated Telephone Company, Pittston, Pa., 1907. In 1908 he became manager of the Jackson (Tenn.) Home Telephone Company, and in 1910 became general manager of the Allen Telephone Properties, which were operating telephone companies in Mississippi, Alabama, and Tennessee. He was later made vice-president and then president of that group of companies. In 1925 he assumed the positions with the Inter-Mountain Telephone Company which he held until his death.

Harris A. Robbins (A'08, M'13) superintendent of power, Brooklyn-Manhattan Transit Corporation, Brooklyn, N. Y., died October 25, 1940. He was born at Southport, N. Y., August 9, 1879, and received the degree of bachelor of science in electrical engineering from Pennsylvania State College im 1901. He was employed by the Brooklyn Rapid Transit Company in 1901 and spent his entire career with that company and its successor, the Brooklyn-Manhattan Transit Corporation. He became assistant erecting engineer in 1903, assistant engineer on electrical design in 1905, and in 1907 was placed in charge of electrical design and construction of power station and substations. Since 1909 he had held the position of superintendent of power. He was also a member of The American Society of Mechanical Engineers and the American Electric Railway Association.

Albert Gall Fuller (A'37) electrician, Phelps Dodge Corporation, Ajo, Ariz., died March 11, 1940, according to information just received. He was born at Los Angeles, Calif., December 21, 1903, and had been engaged in electrical work since 1924. During 1926–27 he was foreman of hydroelectric powerplant number 2 of the City of Los Angeles, Calif. He later was engaged on power house construction for the Southern California Edison Company, Ltd., at Long Beach, Calif.; was in charge of maintenance of electrical equipment for the Mutual Cotton and Oil Company, Phoenix, Ariz.; was employed on construction of powerhouse electrical equipment for the Calumet and Arizona Mining Company. From 1931 to 1934 he engaged in electrical contracting in Los Angeles, and since 1934 had been employed by the Phelps Dodge Corporation.

Joseph Hegy (A'38) San Jose, Calif., died November 5, 1938, according to information just received. He was born at Minneapolis, Minn., June 14, 1907. He received the degree of bachelor of arts in 1935 from Stanford University, and later carried on graduate work in electrical engineering at that institution.

Correction

William G. Quirk (A'16, M'27) engineer, division of street lighting and exterior electrical distribution, Department of Water Supply, Gas, and Electricity, City of New York, N. Y., died September 10, 1939, instead of September 10, 1940, as incorrectly reported in the November issue, page 474.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on November 14, 1940, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Gardett, H. C., chief electrical engineer and general manager, Bureau of Power and Light, Los Angeles, Calif.

1 to Grade of Fellow

To Grade of Member

Anderson, L. G., superintendent of rolling stock and shops, Indianapolis Railways, Indianapolis, Ind.
Bateman, I. L., assistant engineer of distribution, Bureau of Power and Light, Los Angeles, Calif.
Bauman, H. A., assistant superintendent, Brooklyn Edison Company, Brooklyn, N. Y.
Cockaday, L. M., instructor of physics, United States Naval Academy, Annapolis, Md.
DeBlieux, E. V., design engineer, General Electric Company, Pittsfield, Mass.
Dingle, Howard, president, Cleveland Worm and Gear Company, Cleveland, Ohio.
Kleinau, C. S., engineer, Southern California Telephone Company, Los Angeles, Calif.
Marrison, W. A., research engineer, Bell Telephone Laboratories, New York, N. Y.
Matthews, W. J., chief operator, Virginia Electric and Power Company, Fredericksburg, Va.
Montgomery, T. B., control engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Poling, C. V., assistant electrical engineer, Tennessee Valley Authority, Knoxville, Tenn.
Rapp, Stanton, protection engineer, Pacific Telephone and Telegraph Company, San Francisco, Calif.
Smalley, D. F., electrical engineer, General Electric Company, West Lynn, Mass.
Ver Planck, D. W., assistant professor of electrical engineering, Yale University, New Haven, Conn.
Weeks, F. D., assistant engineer, Commonwealth Edison Company, Chicago, Ill.

15 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1940, or February 28, 1941, if the applicant resides outside of the United States or Canada.

United States

1. NORTH EASTERN

Dubinsky, B. A. M., General Electric Company, Schenectady, N. Y.
Foley, E. P., New York, New Haven and Hartford Railroad Company, New Haven, Conn.
Goetzl, M., Central New York Power Corporation, Syracuse, N. Y.
Macintyre, J. R., General Electric Company, West Lynn, Mass.
Spaulding, A. E., General Electric Company, Lynn, Mass.
Walker, I., Walker Electrical Supply Company, Worcester, Mass.
White, J. F., New York, New Haven and Hartford Railroad, New Haven, Conn.

2. MIDDLE EASTERN

Adams, E., City Electrician, Mansfield, Ohio.
Affanasiev, K. I. (Member), Pennsylvania Water and Power Company, Baltimore, Md.
Askin, W. T., United States Navy Department, Cleveland, Ohio.
Clark, O. S. (Member), Copper Wire Engineering Association, Washington, D. C.
Dawson, A. A., Public Service Commission of Virginia, Charleston, W. Va.
Edwards, H. E., Westinghouse Electric and Manufacturing Company, Mansfield, Ohio.
Gore, J. W., Bethlehem Steel Company, Baltimore, Md.
Howard, W. J., Columbus and Southern Ohio Electric Company, Columbus, Ohio.
Jedrziewski, A. A., West Penn Power Company, Greensburg, Pa.
Koslow, J., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Quatman, F. T., North Electric Manufacturing Company, Galion, Ohio.
Raybould, G. M., Reliance Electric and Engineering Company, Cleveland, Ohio.
Richmond, N. B., The Autocall Company, Shelby, Ohio.
Silberman, A. H., Philadelphia Electric Company, Philadelphia, Pa.
Stephens, R. L., Navy Department, Bureau of Ships, Washington, D. C.
Warford, H. S., Westinghouse Electric and Manufacturing Company, Philadelphia, Pa.

3. NEW YORK CITY

Barker, G. A. (Member), Johns-Mansville Sales Corporation, New York, N. Y.
Richna, O. L., Arma Corporation, Brooklyn, N. Y.
Hight, S. C., Bell Telephone Laboratories, New York, N. Y.
Humber, J. H., Arnessen Electric Company, New York, N. Y.
Miller, R. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Monti, L. P. (Member) Underwriters' Laboratories, Inc., New York, N. Y.
Moore, J. A. (Member), Board of Transportation, BMT Division, Brooklyn, N. Y.
Orfaunes, C. J. G., Public Service Electric and Gas Company, Newark, N. J.
Parkinson, G., Gibbs and Cox, Inc., New York, N. Y.
Pearson, H. A., Sonotone Corporation, Elmsford, N. Y.
St. John, J. H., Heyer Products Company, Belleville, N. J.

4. SOUTHERN

Hardin, L. H. (Member), South Carolina Public Service Authority, Charleston, S. C.
King, L. A., Clemson College, Clemson, S. C.
McSwain, E. G., Oxford Orphanage, Oxford, N. C.

5. GREAT LAKES

Bailey, J. L., Southeastern Indiana Power Company, Shelbyville, Ind.
Comee, L. M., Cutler-Hammer, Inc., Milwaukee, Wis.
Gremillion, B. X. (Member), Indiana Bell Telephone Company, Indianapolis, Ind.
Morton, J. H. (Member), Consulting Engineer, Detroit, Mich.
Oliphint, J. W., Westinghouse Electric and Manufacturing Company, Detroit, Mich.
Rutemiller, O. G. (Member), Westinghouse Electric and Manufacturing Company, Detroit, Mich.
Taylor, O. R., American Telephone and Telegraph Company, Chicago, Ill.
Tighe, T. J., General Electric Company, Jackson, Mich.
Winter, L. A. (Member), Buell and Winter Engineering Company, Sioux City, Iowa.
Youngdahl, C. H., Carnegie-Illinois Steel Company, Chicago, Ill.

6. NORTH CENTRAL

Kenyon, J. S., Public Service Company of Colorado, Denver, Colo.
Thomas, D., Loup Power District, Columbus, Nebr.

7. SOUTH WEST

Barnard, C. F., General Electric X-Ray Corporation, Tulsa, Okla.
Cuadra, M. J., Missouri Gas and Electric Service Company, Lexington, Mo.
Curry, O. B., Kansas Gas and Electric Company, Wichita, Kans.
Baton, C. B., Texas Electric Service Company, Eastland, Tex.
Forsman, M. J. American Smelting and Refining Company, El Paso, Tex.
Plog, K., American Telephone and Telegraph Company, Wichita, Kans.

8. PACIFIC

Tillin, I., East Bay Transit Company, Oakland, Calif.

9. NORTH WEST

Gallotte, W. A., Puget Sound Power and Light Company, Seattle, Wash.
Kucera, C. F., Washington Water Power Company, Spokane, Wash.
Madden, G. T., Puget Sound Power and Light Company, Seattle, Wash.
Small, L. C., Washington Water Power Company, Spokane, Wash.

10. CANADA

Hobbs, G. P., Defence Industries, Limited, Nobel, Ont.
Noakes, F., University of Toronto, Toronto, Ont.
Partello, T. E., Hydro Electric Power Commission, Toronto, Ont.

Total, United States and Canada, 63

Elsewhere

Mahmud, S. S., Public Works Department, Mohlan, Sheikhupura, India.
Palmer, W. C., Frontino Gold Mines Limited, Segovia, Antioquia, Republic of Colombia.

Total, elsewhere, 2

Of Current Interest

National Resources Board Seeks Roster of Scientific Personnel

According to information recently released over the signature of Leonard Carmichael, director, the United States Government through the National Resources Planning Board is now engaged in developing a "Roster of Scientific and Specialized Personnel for the purpose of providing a comprehensive list of highly trained Americans possessing special ability in their respective fields." The roster is reported as being jointly administered by the National Resources Planning Board and the United States Civil Service Commission, with representatives of the National Research Council, the Social Science Research Council, the American Council of Learned Societies, the American Council on Education, and other national societies as members of an advisory committee. James C. O'Brien of the staff of the United States Civil Service Commission is listed as executive officer of the project, and Leonard Carmichael is listed as director.

The information necessary for the development of the proposed roster is being secured through the circulation of questionnaires in various engineering, scientific, and technical channels. Although the letter of transmittal with the questionnaire now being circulated through electrical-engineering channels makes no reference to national defense, national defense was the basis of assistance and co-operation recently requested of President R. W. Sorensen and National Secretary H. H. Henline of AIEE incidental to the preparation of the "technical check list" and distribution of it and the Planning Board's questionnaire for electrical engineers. In this assistance and co-operation these officers have made no direct or implied obligation upon the membership, as each member of course has the privilege of handling his questionnaire as he sees fit.

Committee for Child Refugees Will Continue Work

To learn first hand the attitude of the British government toward the evacuation of children from the war zone, Eric H. Biddle, vice-president and executive director of the United States Committee for the Care of European Children, Inc., recently made an air trip to England for conferences with British authorities and other persons active in public life. Mr. Biddle has reported that he "received the most eloquent evidence of the warm appreciation which leaders of the government of Great Britain feel for the generosity of the American people in offering thousands of homes for British children."

It is Mr. Biddle's opinion that some official program for the overseas evacuation of British children, suspended for the time being because of weather and other hazards in the North Atlantic, will be resumed in the spring of 1941. Meanwhile, a limited number of children will be sent by their parents on regular passenger sailings. Hence, the activities of the United States Committee (*EE, Sept. '40, p. 382*) are to be continued.

The Committee, Mr. Biddle's report states, "will keep a relatively small staff on duty at its national headquarters, 215 Fourth Avenue, New York, N. Y., to carry out its continuing responsibilities for the children who have come to this country under its auspices. . .

"The Committee is now responsible to the parents in England for 1,000 children . . . and has a moral responsibility for at least 3,000 other children who have arrived independently. . . . The young guests who have been brought here under the auspices of the United States Committee have been placed in 40 different communities, with New York, N. Y., Boston, Mass., Rochester, N. Y., Worcester, Mass., Philadelphia, Pa., and Canton, Ohio, having received the greatest numbers.

"The United States Committee is studying the possibilities of evacuation of children from countries in the war zone other than Great Britain. Enormous practical difficulties stand in the way, but all possibilities will be studied."

Education • • •

Defense Training for Engineers To Be Financed by Government

A $9,000,000 program for intensive training of personnel for the defense needs of Government and industry in the United States is to be carried on through qualified engineering schools, according to recent announcement from the Federal Security Agency, United States Office of Education.

Text of the announcement follows.

Accepting the almost unanimous offers of American engineering schools to assist in the training of defense personnel, Paul V. McNutt, administrator of the Federal Security Agency, today announced plans for the establishment in qualified educational institutions of special courses, to be given at Government expense, for the intensive training of over 30,000 students with technical backgrounds, to meet future needs of both industry and Government in carrying out the defense program.

Funds to finance this program were voted by Congress in the recent supplementary defense appropriation act, which provides $9,000,000 to be expended for this purpose under the direction of John W. Studebaker, United States commissioner of education, who is also giving general supervision to a companion program of vocational training in the nation's vocational schools. Allotments will be made to the co-operating institutions to meet expenses incurred in giving instruction under the plan.

Courses of study will be given by the colleges both for those able to devote their entire time to preparation for future defense jobs and for workers now employed who desire to fit themselves for more responsible assignments. All instruction will be of college grade equivalent to that given regular candidates for a degree, but the special courses, which will require from two to eight months of study, will concentrate upon training of immediate practical application to specific defense jobs. Classes will be held both at the engineering schools and in or near industrial plants for the benefit of part-time and evening students. The regular college teaching staffs will be supplemented by additional teachers, including specially qualified men from the industries to be served.

TYPE OF TRAINING

Actual and potential needs for additional technical and supervisory personnel will determine the specific courses to be offered and every effort will be made to maintain a continuous balance between the supply of trainees and demands for their services. The first courses to be established will be designed to forestall potential shortages of inspectors of materials, chemicals, explosives, instruments, and power units; designers of machinery, equipment, tools and dies, and aircraft power plants, structures, and instruments; production engineers and supervisors; physical metallurgists; marine engineers and naval architects. As other needs become apparent, additional courses will be added to this program.

Qualifications for enrollment will be determined by the institutions giving the courses in accordance with general rules suggested by the United States Office of Education. In most cases, students will be selected from those who have previously had some technical training or its equivalent in practical experience which must be refreshed or supplemented to fit them to perform specific technical or supervisory duties. The program will not conflict with the vocational training courses also being administered by the Office of Education through the several State boards for vocational education, nor will it displace regular undergraduate courses given by the co-operating colleges.

COLLEGES SUGGEST COURSES

Participation in the program is limited to institutions that offer regular engineering curricula leading to a degree and which operate under charters exempting them from taxation. About 150 engineering schools in State universities, land-grant colleges, and private colleges and universities are eligible. Those desiring to take part have already been invited to submit preliminary plans stating the need for trained technicians in

their areas, the facilities and personnel they have available for giving the necessary courses, the number of students that can be taught, and the approximate cost of instruction. These purposes will be adjusted to a co-ordinated plan for the country as a whole, after which authorization will be given to proceed with the enrollment of students. An announcement of the first courses to be offered, and the institutions where they will be available, will be made about November 15, and instruction should begin shortly thereafter.

Federal allotments to the participating colleges may be used to meet the costs of salaries, materials and supplies, reference books, the operation of buildings, the maintenance and repair of equipment, and, to a limited extent, the purchase or rental of additional equipment and the leasing of space in noncollege buildings. No expenditures are authorized for the purchase or construction of buildings, nor is provision made to defray the living expenses of students. Students will pay no tuition charges.

DEFENSE NEEDS STUDIED

The training program is the outgrowth of several months of preliminary investigation by the United States Office of Education into needs for technically trained personnel. During the past summer a preliminary survey of the situation was made by Andrey A. Potter, dean of the school of engineering of Purdue University, working with Federal agencies and with industries in the defense program. This is now being supplemented by sample investigations in specific areas, including New York City, Philadelphia, Pittsburgh, Chicago, and San Francisco, under the direction of Dean Potter, H. P. Hammond, dean of engineering, Pennsylvania State College; Thorndike Saville, dean of engineering, New York University; and Professor B. M. Woods, department of mechanical engineering, University of California. The data so obtained will guide in determining the first courses to be given, and the methods to be used in determining further needs.

Further to determine training needs as they develop, the Office of Education has just completed arrangements under which selected colleges and universities have made available 22 regional advisers (see accompanying table) who will serve without compensation. Each of these will act, within his own territory, as a liaison officer maintaining continual contact with defense industries, Army and Navy district offices, employment services, and other sources of information on personnel needs, as well as with local engineering schools equipped to meet demands for training courses as they arise. These men will keep the Washington headquarters continually informed so that deficiencies in any one region may be met, if necessary, by training students in other places where facilities are available. In this way a national program will be evolved that will continually adjust itself to changing conditions both in industry and as regards the technical personnel requirements of the Federal Government. Authorization of courses not only will conform to the needs so developed, but also will take into account the staff, equipment, and buildings at the various institutions and the availability of qualified students.

As the program develops arrangements will be made to facilitate the placement of students in defense positions as they complete their training. Much of this will be done by direct contacts between the engineering schools and near-by industries, but students will also have available the facilities of State and Federal employment offices and the United States Civil Service Commission.

Closely co-operating in the development of the program is the advisory committee on engineering training for national defense, the appointment of which was announced by Commissioner Studebaker on September 26 (*EE, Nov. '40, p. 478*). Assisting Commissioner Studebaker and Doctor Fred J. Kelly, chief of the division of higher education, under whose immediate jurisdiction the program falls, will be a small staff of specialists now being selected.

Engineering Defense Training—Regional Advisers

Adviser	Institution	Area for Supervision	Region Number
Dean E. L. Moreland	Massachusetts Institute of Technology, Cambridge	Maine, Massachusetts, New Hampshire, and Vermont	1
Prof. L. E. Seeley	Yale University, New Haven, Conn.	Connecticut and Rhode Island	2
Dean S. C. Hollister	Cornell University, Ithaca, N. Y.	New York State (except New York City)	3
Dean J. W. Barker	Columbia University, New York, N. Y.	New York City and Long Island	4
Pres. A. R. Cullimore	Newark College of Engineering, Newark, N. J.	Northern New Jersey	5
W. T. Spivey	Drexel Institute of Technology, Philadelphia, Pa.	Eastern Pennsylvania, southern New Jersey, and Delaware	6
Dean S. S. Steinberg	University of Maryland, College Park	District of Columbia and eastern Maryland	7
Dean Blake R. Van Leer	North Carolina State College, Raleigh	North Carolina, South Carolina, and Virginia	8
Prof. J. E. McDaniel	Georgia School of Technology, Atlanta	Alabama, Florida, Georgia, Mississippi, and eastern Tennessee	9
Dean F. L. Wilkinson, Jr.	University of Louisville, Louisville, Ky.	Kentucky, Southern Ohio, and southwestern half of West Virginia	10
J. D. Beatty	Carnegie Institute of Technology, Pittsburgh, Pa.	Western half of Pennsylvania, northeastern half of West Virginia and western Maryland	11
Dean C. E. MacQuigg	Ohio State University, Columbus	Northern half of Ohio	12
Dean H. B. Dirks	Michigan State College, Lansing	Southern Michigan	13
Pres. D. B. Prentice	Rose Polytechnic Institute, Terre Haute, Ind.	Indiana (except for Chicago industrial area)	14
Pres. H. T. Heald	Illinois Institute of Technology, Chicago	Illinois, southern Wisconsin, and the Chicago industrial area in Indiana	15
Prof. H. O. Croft	University of Iowa, Iowa City	Iowa, Minnesota, Nebraska, North Dakota, South Dakota, northern Wisconsin, and northern Michigan	16
Dean R. A. Seaton	Kansas State College, Manhattan	Arkansas, Kansas, Missouri, Oklahoma, western Tennessee	17
Dean W. R. Woolrich	University of Texas, Austin	Louisiana and Texas (east of Pecos River)	18
Pres. M. P. Coolbaugh	Colorado School of Mines, Golden	Colorado and Wyoming	19
Prof. R. L. Daugherty	California Institute of Technology, Pasadena	Arizona, New Mexico, southern California, and Texas (west of Pecos River)	20
Dean S. B. Morris	Stanford University, Stanford University, Calif.	Northern California, Nevada, and Utah	21
Prof. H. H. Langdon	State College of Washington, Pullman	Idaho, Montana, Oregon, and Washington	22

Lighting Conference at University of Texas. The College of Engineering at the University of Texas, Austin, will sponsor the first Southwest Lighting Conference, to be held at the University January 9–11, 1941. Fluorescent light sources and their application and other recent developments in lighting techniques will be featured on the program. Conference participants will include members of the southwest section of the Illuminating Engineering Society, architects, representatives of the lighting industry, and members of the Texas State Department of Health.

Notes on List of Accredited Curricula

(See Facing Page)

(*a*). Accrediting applies to both the day and evening curricula.

(*b*). Accrediting applies to the 4-year and 5-year curricula leading to the bachelor of science degree.

(*c*). Accrediting applies to day curriculum only. Action on evening curriculum deferred pending granting of degrees.

(*d*). Accrediting applies only to curriculum as submitted to ECPD and upon completion of which a certificate is issued by Harvard University certifying that the student has pursued such a curriculum.

(*e*). The accrediting of a curriculum in general engineering implies satisfactory training in engineering sciences and in the basic subjects pertaining to several fields of engineering; it does not imply the accrediting, as separate curricula, of those component portions of the curriculum such as civil, mechanical, or electrical engineering that are usually offered as complete professional curricula leading to degrees in these particular fields.

(*f*). On July 24, 1940, Illinois Institute of Technology was formed by the consolidation of Armour Institute of Technology and Lewis Institute. Curricula now listed under Illinois Institute of Technology were formerly listed under Armour Institute of Technology.

List of Undergraduate Curricula Accredited by ECPD as of October 24, 1940

(Subject to revision. For basis of accrediting see ELECTRICAL ENGINEERING, December 1938, page 515, report of ECPD eighth annual meeting elsewhere in this issue.)

University of Alabama: Aeronautical, civil, electrical, industrial, mechanical, mining

Alabama Polytechnic Institute: Electrical, mechanical

University of Alaska: Civil

University of Arizona: Civil, electrical, mechanical, mining

University of Arkansas: Civil, electrical, mechanical

Brooklyn Polytechnic Institute: Chemical (day and 8-year evening), civil (*a*), electrical (*a*), mechanical (*a*)

Brown University: Civil, electrical, mechanical

Bucknell University: Civil, electrical, mechanical

University of California: Civil, electrical, mechanical, metallurgical (metallurgy), mining, petroleum

California Institute of Technology: Aeronautical (5- and 6-year courses), chemical (5-year course), civil, electrical, mechanical

Carnegie Institute of Technology: Chemical, civil (*a*), electrical (*a*), industrial (management) (*a*), mechanical (*a*), metallurgical (*a*)

Case School of Applied Science: Chemical, civil, electrical, mechanical, metallurgical

Catholic University of America: Aeronautical, architectural, civil, electrical

University of Cincinnati: Aeronautical, chemical, civil, electrical mechanical.

The Citadel: Civil

Clarkson College of Technology: Chemical, civil, electrical, mechanical

Clemson Agricultural College: Civil, electrical, mechanical

College of the City of New York (*a*)**:** Civil, electrical, mechanical

University of Colorado: Architectural, civil, electrical, mechanical

Colorado School of Mines: Geological, metallurgical, mining, petroleum

Colorado State College: Civil, electrical, mechanical

Columbia University (*b*)**:** Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

University of Connecticut: Civil, electrical

Cooper Union Institute of Technology (*c*)**:** Civil, electrical, mechanical

Cornell University: Chemical, civil, electrical, industrial (administrative), mechanical

Dartmouth College: Civil

University of Delaware: Civil, electrical, mechanical

University of Denver: Electrical

University of Detroit: Aeronautical, architectural, chemical, civil, electrical, mechanical

Drexel Institute: Chemical, civil, electrical, mechanical

Duke University: Civil, electrical, mechanical

University of Florida: Civil, electrical, industrial, mechanical

Georgia School of Technology: Aeronautical, chemical (including co-operative curriculum), civil, electrical, mechanical

George Washington University: Civil, electrical, mechanical

Harvard University (*d*)**:** Civil, communication, electrical, industrial (engineering and business administration), mechanical, metallurgical (physical metallurgy), sanitary

University of Idaho: Civil, electrical, mechanical, metallurgical (metallurgy), mining

University of Illinois: Architectural, ceramic (technical option), chemical, civil, railway civil, electrical, railway electrical, general (*e*) mechanical, railway mechanical, metallurgical, mining

Illinois Institute of Technology (Armour College of Engineering) (*f*)**:** Chemical, civil, electrical, mechanical

Iowa State College: Agricultural, architectural, ceramic, chemical, civil, electrical, general (*e*), mechanical

State University of Iowa: Chemical, civil, electrical, mechanical

Johns Hopkins University: Chemical, civil, electrical, mechanical

University of Kansas: Architectural, civil, electrical, mechanical, mining

Kansas State College: Agricultural, architectural, civil, electrical, mechanical

University of Kentucky: Civil, electrical, mechanical, metallurgical, mining

Lafayette College: Civil, electrical, industrial (administrative), mechanical, metallurgical, mining

Lehigh University: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Louisiana State University: Chemical, civil, electrical, mechanical, petroleum

University of Louisville: Chemical, civil, electrical, mechanical

University of Maine: Civil, electrical, general (*e*), mechanical

Manhattan College: Civil, electrical

Marquette University: Civil, electrical, mechanical

University of Maryland: Civil, electrical, mechanical

Massachusetts Institute of Technology: Aeronautical, building engineering and construction, chemical, civil, electrical, electrochemical, general (*e*), industrial (business and engineering administration), mechanical, metallurgical (metallurgy), naval architecture and marine engineering (including marine transportation), public health, sanitary

University of Michigan: Aeronautical, chemical, civil, electrical, engineering mechanics, mechanical, metallurgical, naval architecture and marine engineering, transportation

Michigan College of Mining and Technology: Civil, electrical, mechanical, metallurgical, mining

Michigan State College: Civil, electrical, mechanical

University of Minnesota: Aeronautical, chemical, civil, electrical, mechanical, metallurgical, mining, petroleum

University of Missouri: Chemical, civil, electrical, mechanical

Missouri School of Mines and Metallurgy: Ceramic, civil, electrical, metallurgical, mining (mine) (including petroleum option)

Montana School of Mines: Geological, metallurgical, mining

Montana State College: Civil, electrical, mechanical

University of Nebraska: Agricultural, architectural, civil, electrical, mechanical

University of Nevada: Electrical, mechanical, mining

University of New Hampshire: Civil, electrical, mechanical

University of New Mexico: Civil, electrical, mechanical

New Mexico State College: Civil, electrical, mechanical

New Mexico School of Mines: Geological (both mining and petroleum options), metallurgical, mining, petroleum

New York University: Aeronautical, chemical (day and 7-year evening), civil (*a*), electrical (*a*), industrial (administrative), mechanical

New York State College of Ceramics (at Alfred University): Ceramic

Newark College of Engineering: Civil, electrical, mechanical

North Carolina State College: Ceramic, civil, electrical, mechanical

University of North Dakota: Chemical, civil, electrical, mechanical, mining

North Dakota Agricultural College: Architectural, mechanical

Northeastern University: Civil, electrical, industrial, mechanical

Northwestern University: Civil, electrical, mechanical

Norwich University: Civil, electrical

Ohio State University: Ceramic, chemical, civil, electrical, industrial, mechanical, metallurgical, mining (mine)

University of Oklahoma: Architectural, chemical, civil, electrical, mechanical, petroleum

Oklahoma Agricultural and Mechanical College: Civil, electrical, industrial, mechanical

Oregon State College: Civil, electrical, mechanical

University of Pennsylvania: Chemical, civil, electrical, mechanical

Pennsylvania State College: Architectural, ceramic (ceramics), chemical, civil, electrical, electrochemical, fuel technology, industrial, mechanical, metallurgical (metallurgy), mining, petroleum and natural gas, sanitary

University of Pittsburgh: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining, petroleum

Pratt Institute: Electrical, mechanical

Princeton University: Chemical, civil, electrical, mechanical

Purdue University: Chemical, civil, electrical, mechanical

Rensselaer Polytechnic Institute: Aeronautical, chemical, civil, electrical, industrial, mechanical, metallurgical

Rhode Island State College: Civil, electrical, mechanical

Rice Institute: Civil, electrical, mechanical

University of Rochester: Mechanical

Rose Polytechnic Institute: Civil, electrical, mechanical

Rutgers University: Civil, electrical, mechanical, sanitary

University of Santa Clara: Civil, electrical, mechanical

South Dakota State College: Civil, electrical, mechanical

South Dakota State School of Mines: Civil, electrical, metallurgical, mining

University of Southern California: Petroleum

Southern Methodist University: Civil, electrical, mechanical

Stanford University: Civil, electrical, mechanical, metallurgical, mining, petroleum

Stevens Institute of Technology (*e*)**:** General

Swarthmore College: Civil, electrical, mechanical

Syracuse University: Chemical, civil, electrical, industrial (administrative), mechanical

University of Tennessee: Chemical, civil, electrical, mechanical

University of Texas: Architectural, civil, electrical, mechanical, petroleum (petroleum production)

Agricultural and Mechanical College of Texas: Civil, electrical, mechanical, petroleum (4- and 5-year courses)

Texas Technological College: Civil, electrical, mechanical

Tufts College: Civil, electrical, mechanical

Tulane University of Louisiana: Civil, electrical, mechanical

University of Tulsa: Petroleum (including options in refining and production)

Union College: Civil, electrical

United States Coast Guard Academy (*e*)**:** General

University of Utah: Civil, electrical, mechanical, metallurgical, mining

Utah State Agricultural College: Civil

Vanderbilt University: Civil, electrical, mechanical

University of Vermont: Civil, electrical, mechanical

University of Virginia: Civil, electrical, mechanical

Virginia Military Institute: Civil, electrical

Virginia Polytechnic Institute: Ceramic, chemical, civil, electrical, industrial, mechanical

Washington University: Architectural, civil, electrical, industrial (administrative), mechanical

University of Washington: Aeronautical, ceramic, chemical, civil, electrical, mechanical, metallurgical, mining

State College of Washington: Architectural, civil, electrical (basic and hydroelectric options), mechanical (basic option), metallurgical, mining

Webb Institute of Naval Architecture: Naval architecture and marine engineering

West Virginia University: Civil, electrical, mechanical, mining

University of Wisconsin: Chemical, civil, electrical, mechanical, metallurgical, mining

Worcester Polytechnic Institute: Civil, electrical, mechanical

Yale University: Chemical, civil, electrical, mechanical, metallurgical (metallurgy)

Honors • • • •

John Fritz Medal Awarded to Ralph Budd

The John Fritz Medal, conferred by the four national societies of civil, electrical, mechanical, and mining and metallurgical engineers in recognition of notable scientific and industrial achievement, has been awarded for 1941 to Ralph Budd, president of the Chicago, Burlington, and Quincy Railroad, for "improvement of railroad tracks and service, especially the introduction of lightweight streamlined trains."

Mr. Budd was born August 20, 1879, at Waterloo, Iowa, and received the degree of bachelor of science in civil engineering at Highland Park College in 1899. He was with the engineering department of the Chicago Great Western Railway, 1899–1902, and with the Chicago, Rock Island, and Pacific Railway, 1902–06, advancing to division engineer. From 1906 to 1909 he was chief engineer of the Panama Railroad, and from 1909 to 1912 chief engineer of the Oregon Trunk Railway, Spokane, Portland, and Seattle Railway, and the Spokane and Inland Empire Railroad. He went with the Great Northern Railway in 1913 as assistant to the president and chief engineer, becoming executive vice-president in 1918 and president in 1919. Since 1932 he has been president of the Chicago, Burlington, and Quincy Railroad and its various subsidiaries. During 1930 he inspected and reported upon rehabilitation of railways in the Soviet Union. He is a member of the American Society of Civil Engineers, American Railway Engineering Association, and Western Society of Engineers.

Regarded as the highest honor of the engineering profession, the John Fritz Medal is awarded not oftener than once a year, without restriction on account of nationality or sex, by a joint board composed of four members from each of the founder societies. AIEE representatives on the present board, all past presidents, are: A. M. MacCutcheon (A'12, F'26), W. H. Harrison (A'20, F'31), John C. Parker (A'04, F'12), F. M. Farmer (A'02, F'13).

Other Societies •

NRC Insulation Conference Held in Washington, D. C.

With a registered attendance of 102, the 13th annual session of the National Research Council's conference on electrical insulation was held in Washington, D. C. from October 30 to November 2, 1940. The Friday morning technical session was held at the National Bureau of Standards, the other three technical sessions were held in the National Research Council's rooms in the National Academy of Sciences building.

The opening general session was addressed by Doctor Ross G. Harrison, chairman of National Research Council, and by Doctor Vannevar Bush, vice-chairman of NRC's division of engineering and industrial research and chairman of the National Defense Research Commission. Doctor Harrison briefly outlined the 77-year history of the National Academy of Sciences and explained the relationship of National Research Council as the Academy's operating agency. He pointed out that National Research Council, set up in 1916 as a consulting body to study the scientific aspects of World War problems, was made a permanent organization in 1918 to stimulate research on national defense and other problems of broad importance. Doctor Bush explained more of Council's activities, pointing out that it functions to bring together diverse groups of scientific thought, with special emphasis on problems of national significance. In necessarily general terms Doctor Bush indicated something of the scope and importance of Council's work incidental to current national defense problems and its co-operation with such other vital agencies as the National Advisory Committee on Aeronautics and the National Defense Research Commission, a suborganization of the Council of National Defense, the purpose of which is to accelerate civilian research for the benefit of government.

By official action, Doctor Ward F. Davidson (A'14, F'26) director of research for the Consolidated Edison Company of New York, Inc., will continue as chairman of the insulation conference. With new appointments and holdover officers, the executive committee of the conference now is constituted as follows:

W. F. Davidson, Consolidated Edison Company, New York, N. Y., chairman

S. O. Morgan, Bell Telephone Laboratories, New York, vice-chairman

Thorstein Larsen, Consolidated Edison Company, New York, secretary

H. H. Race, General Electric Company, Schenectady, N. Y., chairman, committee on physics

Arthur von Hipple, Massachusetts Institute of Technology, Cambridge, vice-chairman, committee on physics

R. N. Evans, Consolidated Edison Company, New York, chairman, committee on chemistry

G. T. Kohman, Bell Telephone Laboratories, New York, vice-chairman, committee on chemistry

C. F. Hill, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa., chairman, committee on monographs

H. N. Curtis, Bureau of Standards, Washington, D. C.

W. A. Del Mar, Phelps Dodge Copper Products Corporation, Yonkers, N. Y.

J. B. Whitehead, The Johns Hopkins University, Baltimore, Md.

Continuing its customary practice, the conference included on its Washington program 22 informal technical presentations in the nature of progress reports indicating the status and trend of physical, chemical, and electrical research of significance in the field of electrical insulation. It is expected that a comprehensive report reflecting the nature and scope of the material presented at Washington will be available for an early issue of ELECTRICAL ENGINEERING.

The date and location of the 1941 conference was left open, pending developments.

ECPD Elects Officers at Annual Meeting

At the 1940 annual meeting of the Engineers' Council for Professional Development held on October 24 at the University Club, Pittsburgh, Pa., R. E. Doherty (A'16, F'39) president, Carnegie Institute of Technology, was elected chairman and Harry T. Woolson, executive engineer, the Chrysler Corporation, was elected vice-chairman. George T. Seabury, secretary of the American Society of Civil Engineers, becomes secretary and H. H. Henline (A'19, M'26) national secretary, AIEE, assistant secretary. The following committee chairmen also were elected at the Pittsburgh meeting:

A. A. Potter, past president, The American Society of Mechanical Engineers, *committee on engineering schools*

Charles F. Scott (A'92, F'25, HM'29) past president AIEE, Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners, *committee on professional recognition*

R. L. Sackett, past president, SPEE, *committee on student selection and guidance*

S. D. Kirkpatrick, editor, *Chemical and Metallurgical Engineering, committee on professional training*

B. R. Needles, of Ash-Howard-Needles and Tammen, New York, N. Y., *ways and means committee.*

ENGINEERING INSTITUTE OF CANADA BECOMES MEMBER

By unanimous vote of the Council, the Engineering Institute of Canada became the eighth participating body of ECPD. A delegation of members of the Institute, headed by Past President J. B. Challies, was present. Dr. Challies, speaking on behalf of the president of the EIC, expressed the Institute's appreciation of the action by which it had become more closely affiliated with engineering bodies in the United States and announced the names of the Institute's representatives: J. M. R. Fairbairn, A. Surveyer, and J. B. Challies, all past presidents of the Institute. He also introduced the other members of the delegation, Professor C. R. Young, of the University of Toronto, who was appointed to the commit-

Future Meetings of Other Societies

American Association for the Advancement of Science. December 27, 1940–January 2, 1941, Philadelphia, Pa.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 17–20, 1941, New York, N. Y.

American Mathematical Society. 47th Annual Meeting, December 31, 1940–January 1, 1941, New Orleans, La.

American Physical Society. 238th meeting, December 1940, Pasadena, Calif.

239th meeting (annual), December 26–28, 1940, Philadelphia, Pa.

240th meeting, February 21–22, 1941, Cambridge, Mass.

American Society of Civil Engineers. Annual meeting, January 15–18, 1941, New York, N. Y.

American Society for Testing Materials. Spring meeting, March 3–7, 1941, Washington, D. C.

American Society of Heating and Ventilating Engineers. 47th annual meeting, January 27–29, 1941, Kansas City, Mo.

Engineering Institute of Canada. Annual meeting, February 6–7, 1941, Hamilton, Ont., Canada.

Institute of Radio Engineers. 16th annual convention, January 9–11, 1941, New York, N. Y.

National Exposition of Power and Mechanical Engineering. 14th. December 2–7, 1940, New York, N. Y.

Society of Automotive Engineers. Annual meeting, January 6–10, 1941, Detroit, Mich.

tee on professional training; H. F. Bennett, who becomes a member of the committee on student selection and guidance; and L. Austin Wright, general secretary, EIC. James A. Vance, who was not present, will serve on the committee on professional recognition.

REPORTS STATUS OF ACCREDITING

For the committee on engineering schools, whose principal function has been the accrediting of curricula, Dean Potter reported as chairman. Incident to its accrediting program the committee has given advice informally to schools requesting it. As of October 20, 1939, curricula to the number of 433 had been accredited unconditionally, 82 for a limited period, and, 172 had not been accredited. During 1939–40 visits were made to 22 institutions for the purpose of reinspecting 70 curricula on the accredited list, and 17 institutions were visited in order to appraise 32 curricula not on the accredited list. As a result of the year's work and of actions taken on October 24, 1940, the record now stands as follows: Total curricula submitted, including reinspections, 791; accredited unprovisionally, 457; accredited provisionally, 83; not accredited, 164; reinspections resulting in no change in status, 82; action pending, 5. A complete list of accredited curricula appears on page 523.

Competition for 1941 Prizes Announced by EEI Committee

Prizes to be awarded at the 1941 convention of the Edison Electric Institute recently have been announced by means of posters distributed to public-utility operating companies throughout the United States. The awards, contributed by various donors and administered by the prize awards committee of EEI, constitute the electric light and power industry's recognition of outstanding achievements by companies and individuals. Competition is open to all companies and their employees without regard to membership in EEI.

Thirty-three prizes will be awarded, 11 to electric utility companies and 22 to individuals. Most recently established is the Laura McCall Award offered for the first time this year, and consisting of a plaque and two certificates to companies for home-service department achievement in promoting electrical appliances and home lighting, and cash prizes to $100, $50, and $25 to the heads of the departments responsible.

The Augustus D. Curtis Award, for new lighting installations or complete relighting of commercial interiors, has been broadened this year to include use of fluorescent lighting, either entirely or in combination with incandescent sources. The award includes certificates to the companies winning first and second places, and prizes of $200 and $100 respectively to the individuals responsible, as well as third and fourth prizes of $50 and $25 to individuals.

Of particular interest to AIEE members are the Forbes prize, a cash award of $250 for the best paper on public relations in the electric light and power industry, and the McGraw prizes, three awards of $250, $150, and $100, for the best papers on technical or engineering subjects relating to the industry. Any person employed by an electric light and power company may compete.

Full information on all awards may be obtained from the secretary, Edison Electric Institute, 420 Lexington Ave., New York, N. Y. The other awards are:

The Charles A. Coffin Award, a gold medal and a contribution of $1,000 to the employees' benefit fund, to the public-utility operating company showing the greatest over-all advancement in operations and physical plant.

The Thomas W. Martin Award, a bronze plaque, given to the company showing the greatest contribution to progress in rural electrification.

The National Electric Water Heating Award, cash prizes of $500, $300, and $200, to companies for best all-around promotion and sale of electric water heaters.

The George A. Hughes Award, trophy and two certificates of recognition to companies, cash awards of $500, $300, and $200 to individuals responsible, for development of the electric-range market through direct or co-operative promotion or selling.

The R. B. Marshall Award, five cash prizes of $100 each to salesmen representing utility companies, classified in five groups according to number of customers, who sell, lease, or rent the greatest number of domestic electric ranges.

The Claude L. Matthews Awards for Valor, three cash awards of $100 each for acts of outstanding courage performed in maintaining or restoring electric service.

IES Sets up Regional Divisions

As a result of constitutional changes effective October 1, 1940, the Illuminating Engineering Society has established eight territorial divisions, known as "regions". Geographical boundaries have been set according to natural groupings of the sections and chapters of the society. Regional meetings are to be scheduled during the coming year.

Under the new plan, which resembles the setup of the larger national engineering societies, each region will be represented on the society's council by a regional vice-president. Chairmen of sections will no longer be members of the council. For the year 1940–41, vice-presidents have been chosen by nominating committees representing the sections and chapters in each region and confirmed by the council. Beginning in 1941, candidates for regional vice-presidents are to be chosen by regional nominating committees and voted upon by the entire membership. Four vice-presidents will be elected each year, to serve two-year terms.

The regions, and their vice-presidents for 1940–41, are:

Region A, Toronto section, Montreal chapter, non-section territory in Canada; R. M. Love, Canadian General Electric Company, Toronto.

Region B, New England and New York sections; O. P. Cleaver (A'36) Westinghouse Lamp Division, Bloomfield, N. J.

Region C, Philadelphia and Pittsburgh sections, Baltimore-Washington chapter; A. S. Turner, Jr., General Electric Company, Philadelphia, Pa.

Region D, western New York, Cleveland, Ohio Valley, and Michigan sections; A. F. Wakefield, F. W. Wakefield Brass Company, Vermilion, Ohio.

Region E, southeastern United States, including Georgia and New Orleans chapters; R. A. Palmer, Duke Power Company, Charlotte, N. C.

Region F, Chicago and Twin-City sections, Nebraska-Iowa, Heart of America, and Spirit of St. Louis chapters; N. B. Hickox, Chicago, Ill.

Region G, southwestern United States, including southwestern section; F. M. Rutherford, Dallas Power and Light Company, Dallas, Tex.

Region H, Pacific Coast area, including Southern California and San Francisco Bay sections; F. A. Hansen (M'31) Western Institute of Light and Vision, Los Angeles, Calif.

Engineering Section, AAAS, to Hold Annual Meeting

"Economic and Engineering Interests of the Americas" will be the chief theme of the annual meeting of Section M (Engineering) of the American Association for the Advancement of Science, to be held at Philadelphia, Pa., December 31, 1940. The program, arranged in co-operation with Director G. H. Cox, Inter-American Center, The George Washington University, is expected to include addresses on "Aviation Progress" by Doctor Jerome C. Hunsaker, Massachusetts Institute of Technology; "Educational Relationships Between the Americas", by Doctor Clyde Heck Marvin, president, The George Washington University; "The Press and Inter-American Relationships", by Raymond C. Clapper; "Engineering Developments in South America", by Fred Lavis, consulting engineer; "Inter-American Engineering Standards", by C. L. Warwick, secretary, American Society for Testing Materials. Further information about the meeting, which is open to all those interested, may be obtained from F. M. Feiker (M'34), secretary, Section M, AAAS, and dean of the school of engineering, The George Washington University, Washington, D. C.

South American Tour Planned by NRC

Plans are being developed by the National Research Council to have a group of industrial and research executives from the United States visit South American countries early in 1941 to study industrial possibilities and means of interchanging technological developments. The Council has been assured co-operation from the government agencies responsible for inter-American relations. Tours of laboratories in the United States and in several European countries have been sponsored by the Council in previous years.

Industry • • • •

New Standards Bring Smaller Motors

New standards adopted October 1 by the National Electrical Manufacturers Association have reduced the frame sizes of electric motors in sizes from three-quarters to two horsepower. This is said to be the first major change in the original motor-dimension standards adopted by the association members 12 years ago, and represents the culmination of advances in engineering art and materials of motor manufacture achieved during that period. These changes affect weight, space, and size, and are made possible largely by two major improvements: better silicon steels; and new synthetic and cloth insulations having

higher dielectric strength and requiring less space.

Since the adoption of the new standards, both the General Electric Company and the Westinghouse Electric and Manufacturing Company have announced new lines of motors: an entire line of completely new polyphase induction motors in "integral horsepower" sizes by the former; and a series ranging from one-half to three horsepower by the latter. Principal new features of the new motors are: modern "streamlined" appearance; more complete physical protection than heretofore available except in enclosed machines; improved insulation resulting in smaller motor coils; and improved bearing design and lubricating arrangements.

G. B. Cortelyou Dies. George Bruce Cortelyou, retired president of the former Consolidated Gas Company, New York, N. Y. (now part of Consolidated Edison Company of New York) died October 26, 1940. Born at New York, N. Y., July 26, 1862, he received the degrees of bachelor of laws, Georgetown University, 1895, and master of laws, Columbian (now George Washington) University, 1896, and the honorary degree of doctor of laws from several institutions. He entered government service in 1889, serving as secretary to various officials of the Port of New York and the Postoffice Department in New York and later in Washington, D. C. From 1895 to 1901 he was secretary successively to Presidents Cleveland, McKinley, and Theodore Roosevelt, and in 1903 he was appointed by President Roosevelt to the newly created Cabinet position of Secretary of Commerce and Labor, later serving as Postmaster General, and as Secretary of the Treasury. He continued in the last position until the end of the Roosevelt administration. From 1909 until his retirement in 1935 he was president of the Consolidated Gas Company. He was a past president of the American Gas Association, the former National Electric Light Association, and the Edison Electric Institute.

E. T. J. Brandon Dies. Edgar Thomas John Brandon, retired chief electrical engineer of the Hydro Electric Power Commission of Ontario, Toronto, died September 25, 1940. Born at Toronto, December 20, 1880 he received the degree of bachelor of applied science from the University of Toronto in 1901. He was a design engineer for the Ontario Power Company, and later with W. C. Johnson, consulting engineer, both at Niagara Falls, and with Hugh L. Cooper in New York, N. Y., before entering the employ of the Commission in 1908 as a designer. Prior to his retirement on account of ill health in 1938, Mr. Brandon was a Fellow of the AIEE, and active in the Toronto Section, of which he was chairman 1916–17.

G.E. Lightning Generator Dismantled. The 40-ton lightning generator which provided the lightning display at the General Electric Company's Steinmetz Hall at the New York World's Fair was dismantled after the close of the Fair. The equipment was divided, part being sent to the high-voltage laboratory of the National Bureau of Standards, Washington, D.C., for construction of a similar 2,000,000-volt lightning generator, and the remainder replacing equipment now in use at the company's high-voltage laboratory at Pittsfield, Mass.

Electric Pump Wins Plastics Award. An all-molded electric bilge pump received the highest award in the transport group of the fifth annual modern plastics competition sponsored by *Modern Plastics* magazine. Awards were announced in October. Made of Durez, a phenolic plastic, by Oris Manufacturing Company, the pump has high dielectric strength and is resistant to water, oil, and abrasives. The automatic motor-controlled unit handles 70 gallons per ampere hour of battery used. Designed for use on either sail or motor boats 50 feet long or less, the pump is 10 inches high, occupies a floor area $5^1/_2$ by $3^1/_2$ inches, and has a sway-proof switch which turns it on and off as needed, regardless of the motion of the boat.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy as inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

An Analysis of the Unbalanced Wye Circuit

To the Editor:

The unbalanced or unsymmetrical three-phase circuit, either delta- or wye-connected, can be analyzed completely by means of complex-quantity algebra or by graphics. The usual treatment appears to be algebraic, several variations of this form of attack being available in standard textbooks on electrical engineering. However, whereas the unbalanced delta circuit is also discussed by way of graphics, the authors of this discussion never have seen a graphical solution for the general wye circuit. Statements in textbooks often imply the impossibility of such an analysis.

However, the wye-circuit, with no neutral lead, and with unbalanced line voltages and leg impedances, is open readily to graphics. Such a treatment in general does not require greater time in solving a problem than do other methods, and it has the distinct added advantage of permitting visualization of the entire problem and the individual steps as one proceeds. The following graphical method of solving the unbalanced wye circuit is, so far as the authors know, the only one that is *completely* graphical and comparable with the graphical methods obtained for the unbalanced delta circuit.

Figure 1*a* shows an unbalanced wye-connected load receiving its power from a three-phase generator. The line voltage of 100 volts, and the ohmic values of the circuit elements, are chosen to give convenient magnitudes and phase angles. To a voltage scale the full lines of figure 1*b* show the triangle of line voltages and the three component leg voltages with point N being the generator neutral.

If the generator neutral N is connected to the load junction O a current will flow in the neutral line. This current can be determined easily by familiar methods, either graphical or algebraic. When the switch in the neutral line is opened, the neutral current then becomes zero, and a voltage E_{ON} appears across the switch, figure 1*a*. With the neutral of the generating system fixed, the existence of this voltage shows that the potential of point O no longer is the same as that of N, but that O has moved on the vector diagram, as shown by the voltage vector E_{ON} of figure 1*b*. The fundamental problem in the analysis of the unbalanced wye circuit is that of determining the position of O.

If a single-phase voltage were introduced into the neutral line in place of the switch, this voltage being equal in magnitude to E_{ON} and of the same phase, exactly the same circuit conditions would prevail as though the neutral line were open. The analysis thus can be carried out by superposing the results for the balanced leg voltages and those for the single-phase voltage. The single-phase voltage acts on the three leg impedances in parallel, sending a resultant current through them, equal and opposite to the initial neutral current. E_{ON} is merely the product of the initial neutral current and the equivalent impedance of the three legs in parallel. It thus is known directly in magnitude and phase.

The steps in solving the unbalanced wye circuit to determine the location of O are:

1. Determine the magnitude and phase of the neutral current assuming the neutral line closed.
2. Calculate the voltage E_{ON}, in magnitude and phase, which will drive the above current through the three leg impedances connected in parallel.
3. Lay off the voltage E_{ON} in proper phase from the initial point N. The outer end of the vector voltage is the position of O.

The remaining steps in determining the actual leg voltages, currents, phase angles, power components, etc., for the unbalanced wye circuit then follow directly.

The method is illustrated on the circuit of figure 1*a*, and although complex-quantity algebra can be employed wholly or in part, the analysis here is given by graphics. With phase rotation ABC, and positive phase angles measured counterclockwise, the neutral current when the switch is closed is $10/\sqrt{3}$ amperes, figure 2*a*. Conventions with respect to directions of voltage and current and the order of subscripts on these quantities are shown in figure 1*a*.

The voltage E_{ON} which will drive the current $10/\sqrt{3}$ amperes through the parallel combination of the three leg impedances, figure 2*b*, can be obtained by the usual

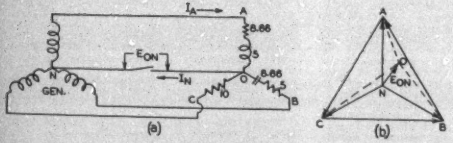


Figure 1. Unbalanced wye-connected load with associated voltage vector diagram

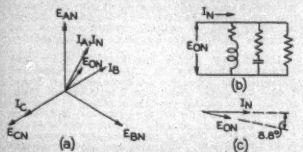


Figure 2. Load circuit of the single-phase voltage E_{ON} with associated vector diagram

graphical method of handling a parallel circuit. It is found to be 24 volts and lags the current I_N by 8.8 degrees, figure 2*c*. Point *O* thus is located upward and to the right from point *N*, figure 1*b*. The vector voltage E_{ON} is 51.2 degrees from the horizontal. As already stated, the remaining steps in determining all quantities now follow immediately.

This method also is applicable to a three-phase system of unequal line voltages. Further, the point *N* can be assumed anywhere, inside or outside the triangle of line voltages. It can, for example, be chosen at *A*, *B*, or *C*, if it appears convenient. The respective parts of the graphical solution are carried out as described, and *O* will be located, regardless of the magnitude or kind of unbalance, or the assumption on the position of *N*. For any particular circuit *O* can have, of course, but one location on the graph and all methods must yield the same result. The several steps in this method perhaps may be carried out more conveniently by complex quantity algebra if one desires. In any case, the scheme visualizes the problem and its component parts, which other methods do not do so successfully.

B. L. ROBERTSON (A'26, M'32)
and L. J. BLACK

(Respectively, associate professor and instructor of electrical engineering, University of California, Berkeley)

Value of a Determinant With Complex Elements

To the Editor:

During the past few years, there have appeared in the literature a number of articles on the application of matrix algebra to electrical problems. In all of these papers, the use of the inverse of a square matrix is involved. This in turn requires the finding of the value of the determinant of the matrix. The determination of the value of a determinant with real elements (that is, with elements which are constants) presents no problem since such determinants have been considered in a course in analytic geometry. A determinant with complex elements, however, is usually new to the reader and the process of determining its value by the ordinary rules of expansion is not only quite laborious for the higher-order determinants, but it might present a problem as to what to do with the complex elements. The purpose of this letter is to suggest three simple methods of reducing a determinant with complex elements to a sum of determinants with real elements only.

"SUM OF TWO DETERMINANTS" METHOD

This method is based upon the fundamental rule for adding two determinants differing only by one column or one row. Only the second order and the third order determinants will be discussed here as the higher order determinants follow directly. Consider a second order determinant

$$\begin{vmatrix} A+jB & C+jD \\ R_{11}+jX_{11} & R_{12}+jX_{12} \\ R_{21}+jX_{21} & R_{22}+jX_{22} \end{vmatrix} \quad (1)$$

If the column containing R_{11}, R_{21} is represented by A, the column containing jX_{11}, jX_{21} by jB, etc., then with this new notation the determinant (1) can be written very simply

$$|A+jB,\ C+jD| \quad (2)$$

Now apply the rule for addition of determinants successively,

$$\begin{aligned} |A+jB,\ C+jD| &= |A,\ C+jD|+|jB,\ C+jD| \\ &= |A,\ C|+|A,\ jD|+ \\ &\quad |jB,\ C|+|jB,\ jD| \end{aligned} \quad (3)$$

If all the elements of any column have a common factor, this factor may be divided out and placed before the new determinant. Then, taking the j and the $j^2=-1$ out, equation 3 becomes

$$\begin{aligned} |A+jB,\ C+jD| &= |A,\ C|-|B,\ D|+ \\ &\quad j|A,\ D|+j|B,\ C| \end{aligned} \quad (4)$$

that is

$$\begin{aligned} \begin{vmatrix} R_{11}+jX_{11}, & R_{12}+jX_{12} \\ R_{21}+jX_{21}, & R_{22}+jX_{22} \end{vmatrix} &= \begin{vmatrix} R_{11}, & R_{12} \\ R_{21}, & R_{22} \end{vmatrix} - \\ &\quad \begin{vmatrix} X_{11}, & X_{12} \\ X_{21}, & X_{22} \end{vmatrix} + j\begin{vmatrix} R_{11}, & X_{12} \\ R_{21}, & X_{22} \end{vmatrix} + j\begin{vmatrix} X_{11}, & R_{12} \\ X_{21}, & R_{22} \end{vmatrix} \end{aligned} \quad (5)$$

Thus, the steps involved are:

1. Expand the determinant with the new notation as shown in (3).
2. Simplify by taking the j's out as shown in (4).
3. Substitute the columns of R's and X's for A, B, C, and D as shown in (5).

To illustrate further this method and the two methods following, next consider the third order determinant,

$$\begin{aligned} \begin{vmatrix} A+jB & C+jD & E+jF \\ R_{11}+jX_{11} & R_{12}+jX_{12} & R_{13}+jX_{13} \\ R_{21}+jX_{21} & R_{22}+jX_{22} & R_{23}+jX_{23} \\ R_{31}+jX_{31} & R_{32}+jX_{32} & R_{33}+jX_{33} \end{vmatrix} &= \\ |A+jB,\ C+jD,\ E+jF| \end{aligned} \quad (6)$$

Following the procedure outlined previously gives

$$\begin{aligned} |A+jB,C+jD,E+jF| &= |A,C+jD,E+jF|+|jB,C+jD,E+jF| \\ &= |A,\ C,\ E+jF|+|A,\ jD,\ E+jF|+|jB,C,\ E+ \\ &\quad jF|+|jB,\ jD,E+jF \\ &= |A,\ C,E|+|A,\ C,\ jF|+|A,\ jD,E|+ \\ &\quad |A,jD,jF|+|jB,C,E|+|jB,\ C,\ jF|+ \\ &\quad |jBjD,E|+|jB,\ jD,\ jF| \\ &= |A,\ C,\ E|-|A,\ D,\ F|-|B,\ C,\ F|-|B,\ D,\ E|+ \\ &\quad j\{|A,\ C,\ F|+|A,\ D,\ E|+|B,\ C,\ E|-|B,D,F|\} \end{aligned} \quad (7)$$

From which

$$\begin{aligned} \begin{vmatrix} A+jB & C+jD & E+jF \\ R_{11}+jX_{11} & R_{12}+jX_{12} & R_{13}+jX_{13} \\ R_{21}+jX_{21} & R_{22}+jX_{22} & R_{23}+jX_{23} \\ R_{31}+jX_{31} & R_{32}+jX_{32} & R_{33}+jX_{33} \end{vmatrix} &= \\ \begin{vmatrix} A & C & E \\ R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{vmatrix} - \begin{vmatrix} A & D & F \\ R_{11} & X_{12} & X_{13} \\ R_{21} & X_{22} & X_{23} \\ R_{31} & X_{32} & X_{33} \end{vmatrix} - \begin{vmatrix} B & C & F \\ X_{11} & R_{12} & X_{13} \\ X_{21} & R_{22} & X_{23} \\ X_{31} & R_{32} & X_{33} \end{vmatrix} - \\ \begin{vmatrix} B & D & E \\ X_{11} & X_{12} & R_{13} \\ X_{21} & X_{22} & R_{23} \\ X_{31} & X_{32} & R_{33} \end{vmatrix} + j\begin{vmatrix} A & C & F \\ R_{11} & R_{12} & X_{13} \\ R_{21} & R_{22} & X_{23} \\ R_{31} & R_{32} & X_{33} \end{vmatrix} + j\begin{vmatrix} A & D & E \\ R_{11} & X_{12} & R_{13} \\ R_{21} & X_{22} & R_{23} \\ R_{31} & X_{32} & R_{33} \end{vmatrix} + \\ j\begin{vmatrix} B & C & E \\ X_{11} & R_{12} & R_{13} \\ X_{21} & R_{22} & R_{23} \\ X_{31} & R_{32} & R_{33} \end{vmatrix} - j\begin{vmatrix} B & D & F \\ X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{vmatrix} \end{aligned} \quad (8)$$

The number of determinants on the right-hand side of the equation should be equal to the 2^n where n is the order of the original determinant.

"COMPLEX NOTATION" METHOD

It is interesting to note that the expansion 4 is similar to the form when expanding the product of two complex numbers

$$(A+jB)(C+jD)=AC-BD+ j(AD+BC) \quad (9)$$

This is to be expected since the terms in the expansion of a second-order determinant involve the products of two complex numbers. Likewise, the form 7 will be found similar to that when expanding the product of three complex numbers

$$\begin{aligned} (A+jB)(C+jD)(E+jF) &= ACE-ADF- \\ &\quad BCF-BDE+j(ACF+ADE+BCE- \\ &\quad BDF) \end{aligned} \quad (10)$$

After having determined the form 9 or 10, it is only necessary to follow step 3 as given in the first method.

"COMBINATION" METHOD

Another method of reducing a determinant with complex elements to a sum of determinants with real elements only is to start with the R and X determinants and then form all possible combinations of columns of R's and jX's. That is, replace the columns of R's by their corresponding columns of jX's one at a time, then two at a time, then three at a time, etc. In the case of the third-order determinant, equation 8, start with

$$\begin{vmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{vmatrix}, \quad \begin{vmatrix} jX_{11} & jX_{12} & jX_{13} \\ jX_{21} & jX_{22} & jX_{23} \\ jX_{31} & jX_{32} & jX_{33} \end{vmatrix}$$

Now replace the columns of the R determinant by their corresponding columns of the

X determinant, one at a time. This gives

$$\begin{vmatrix} R_{11} & R_{12} jX_{12} \\ R_{21} & R_{22} jX_{22} \end{vmatrix}, \quad \begin{vmatrix} R_{11} jX_{12} & R_{13} \\ R_{21} jX_{22} & R_{23} \end{vmatrix}, \quad \begin{vmatrix} jX_{11} & R_{12} R_{13} \\ jX_{21} & R_{22} R_{23} \\ jX_{31} & R_{32} jX_{33} \end{vmatrix}$$

Next two columns at a time,

$$\begin{vmatrix} R_{11} jX_{12} jX_{13} \\ R_{21} jX_{22} jX_{23} \\ R_{31} jX_{32} jX_{33} \end{vmatrix}, \quad \begin{vmatrix} jX_{11} jX_{12} R_{13} \\ jX_{21} jX_{22} R_{23} \\ jX_{31} jX_{32} R_{33} \end{vmatrix}, \quad \begin{vmatrix} jX_{11} R_{12} jX_{13} \\ jX_{21} R_{22} jX_{23} \\ jX_{31} R_{32} jX_{33} \end{vmatrix}$$

Then three at a time,

$$\begin{vmatrix} jX_{11} jX_{12} jX_{13} \\ jX_{21} jX_{22} jX_{23} \\ jX_{31} jX_{32} jX_{33} \end{vmatrix}$$

It can be seen that by starting with the R determinant and ending with the X determinant, the result is the eight determinants on the right-hand side of equation 8. The factor before each determinant can be found in the following manner. If the determinant has one column of jX's, the factor is $+j$. If the determinant has two columns of jX's, the factor is $+j^2 = -1$. And if the determinant has three columns of jX's, the factor is $+j^3 = -j$.

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Books Received •

"Experiments With Light". A new manual containing practical problems for students in science has been prepared under the direction of the Illuminating Engineering Society. Designed for use in high-school physics courses, the manual outlines a dozen practical experiments with light which may be worked out by the student with simple low-cost material, locally obtainable or easily built. The book attempts to give a better concept of the fundamentals of light already studied and a knowledge of the practical problems of lighting as an aid to seeing in everyday life. "Experiments With Light" may be obtained from the Illuminating Engineering Society, 51 Madison Avenue, New York, N. Y., at 25 cents per copy.

The following new books are among those recently received at the engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ENGINES OF DEMOCRACY. By R. Burlingame. Charles Scribner's Sons, New York, 1940. 606 pages, illustrated, 9½ by 6 inches, cloth, $3.75. The history of modern America is viewed in the light of its technological advancement. As the developments in metallurgy, electrical communication, power, printing, highways, illumination, chemical synthesis, and so on, are reviewed, their contribution to our present way of life is stressed. The book closes with a discussion of modern trends and of the social inventions that must follow the technical ones. Contains a bibliography, a chronological list of events and inventions, and extensive index.

HANDBOOK OF ENGLISH IN ENGINEERING USAGE. By A. C. Howell. Second edition. John Wiley and Sons, New York, 1940. 433 pages, illustrated, 8 by 5 inches, cloth, $2.50. Presents rules for proper English, covering word selection, sentence construction, style, arrangement, punctuation, and grammar. Succeeding chapters discuss the composition of business letters, reports, and technical magazine articles. Examples from published material are included to demonstrate current practice.

INTRODUCTION TO ELECTRICAL ENGINEERING. By G. V. Mueller. McGraw-Hill Book Company, New York, 1940. 306 pages, illustrated, 9½ by 6 inches, cloth, $2.75. Points out the relations, the mathematical expression of the relations, and the graphical interpretations of the expressions in each type of circuit—electric, magnetic, and dielectric—under transient as well as steady-state conditions. Particular attention is paid to the solution of nonlinear resistance circuits as an approach to the solution of magnetic circuits. Typical oscillograms are used to illustrate important principles. Problems and laboratory experiments.

INVENTORS AND ENGINEERS OF OLD NEW HAVEN. (New Haven Tercentenary Publications.) Edited by R. S. Kirby. New Haven Colony Historical Society, New Haven, Conn., 1939. 111 pages, illustrated, diagrams, 10 by 6 inches, cloth, apply to R. S. Kirby, Yale University. Contains six lectures given under the auspices of the School of Engineering in Yale University. The subjects are: Eli Whitney; early New Haven inventors; early Yale inventors; early Yale engineers; the formative years of New Haven's public utilities; the founding of the Sheffield Scientific School.

TELEVISION BROADCASTING. By L. R. Lohr, with a foreword by D. Sarnoff. McGraw-Hill Book Company, New York, 1940. 274 pages, illustrated, 9 by 6 inches, cloth, $3.00. Discusses various aspects of television broadcasting, including its effect on society; operating techniques and equipment; program considerations, especially the economic, legal, and technical problems; the co-ordination required for presentation; and the advertising potentialities. Appendices contain a typical television script with production directions, and the Federal Communications Commission rules governing stations.

MARINE DIESEL ENGINE STANDARDS. Edited by M. J. Reed and O. A. Sibley. Published by Diesel Engine Manufacturers' Association, New York, N. Y., 1940. 141 pages, diagrams, 9½ by 6 inches, cloth, $2.00. In addition to presenting standard practices for all phases of installation and application of Diesel engines and accessories in marine work, this book also gives information on standard performances and definitions, classification and marine inspection, and includes some statistical material.

TROUBLES OF ELECTRICAL EQUIPMENT. By H. R. Stafford. Second edition. McGraw-Hill Book Company, New York, 1940. 373 pages, illustrated, 9 by 6 inches, cloth, $3.00. Covers the symptoms, causes, and remedy of troubles of the a-c and d-c apparatus found in the average industrial plant. Also includes hints for efficient operation and maintenance. Diagrams are extensively used, and all formulas are illustrated by practical examples.

WILEY TRIGONOMETRIC TABLES. New York, John Wiley and Sons, 1940. 81 pages, tables, 9 by 5½ inches, cloth, $0.75. Aims to present the tables most used by students of trigonometry. The tables are: squares and square roots; constants with their common logarithms; natural logarithms of numbers; five-place logarithms of numbers; logarithms of functions; and four-place values of functions and radians.

VECTOR METHODS, APPLIED TO DIFFERENTIAL GEOMETRY, MECHANICS, AND POTENTIAL THEORY. By D. E. Rutherford. Oliver and Boyd, Edinburgh and London; Interscience Publishers, New York, 1939. 127 pages, diagrams, 7½ by 5 inches, cloth, 4s 6d, $1.50. Intended to provide for undergraduate use a clear account of the abstract theory of the vector calculus and a brief but broad survey of the applications of the theory to various branches of pure and applied mathematics.

THEORY OF GROUP CHARACTERS AND MATRIX REPRESENTATIONS OF GROUPS. By D. E. Littlewood. Oxford University Press, New York; Clarendon Press, Oxford, England, 1940. 292 pages, diagrams, etc., 10 by 6½ inches, cloth, $5.50. Presents a simple, self-contained account of the theory of group characters in its application to finite and continuous matrix groups, and elaborates some of its applications. Preliminary chapters on matrices, algebras, and groups precede the development of the theory. Applications to the theory of symmetric functions and to the structure of groups are dealt with in some detail. In the last two chapters the theory is generalized to certain continuous matrix groups. Bibliography and character tables.

SILVER IN INDUSTRY. Edited by L. Addicks. Reinhold Publishing Corporation, New York, 1940. 699 pages, illustrated, 9 by 6 inches, cloth, $10.00. A summary of three years' research on silver and its industrial applications is presented in 20 chapters written by the editor and others. Topics include physical and mechanical properties, alloys, commercial production, silver-coating methods, electrical and catalytic applications, corrosion properties, and the use of silver in bearings, germicides, photography, coinage, the decorative arts. Bibliography, serial list of United States patents, and classified list of patents of all countries.

MAKING YOUR PHOTOGRAPHS EFFECTIVE. By J. A. Lucas and B. Dudley. McGraw-Hill Book Company (Whittlesey House), New York, 1940. 385 pages, illustrated, 9½ by 6 inches, cloth, $5.00. Discusses all phases of photographic work. Fundamental processes, cameras, and other equipment, darkroom construction, and print making are described; exposures and lighting problems considered; and various methods of work presented.

WEATHER ANALYSIS AND FORECASTING. A Textbook on Synoptic Meteorology. By S. Petterssen. McGraw-Hill Book Company, New York, 1940. 505 pages, illustrated, 9 by 6 inches, cloth, $5.00. Presents modern methods of weather analysis and forecasting. The author discusses in detail the underlying theories and their application to weather charts and upper-air charts, with examples of correct analysis and forecasts. Recent results in air-mass analysis, frontal analysis, and isentropic analysis are included. Bibliography.

AIRCRAFT YEAR BOOK FOR 1940. 22d edition. Edited by H. Mingos. Aeronautical Chamber of Commerce of America, New York, 1940. 532 pages, illustrated, 9 by 6 inches, cloth, $5.00. This annual provides a record of developments in aviation during the past year in the United States and abroad. The work of the Army, Navy, various Federal agencies, and commercial firms is reviewed. Chapters are devoted to the present war, air lines, private flying, airports, training, and other fields of interest. The book includes tables of aircraft specifications, descriptions of aircraft and engine designs, a chronology of events and records, an aeronautical directory, and statistics of the industry.

AEROPLANE INSTRUMENTS, Part I; LANDING LEGS, WHEELS, AND BRAKES; AIRSCREWS, Part I. Aeroplane Maintenance and Operation Series, volumes II, III, and IV. Edited by E. Molloy and E. W. Knott. Chemical Publishing Company, New York, 1940. Each 132 pages, illustrated, 9 by 6 inches, cloth, $2.00 each. Three volumes of a new series on airplane maintenance and operation. "Aeroplane Instruments (Part I)" deals with the operation and maintenance of the Sperry gyropilot, Sperry aircraft instruments, and Smith's aircraft instruments. "Landing Legs, Wheels and Brakes" deals with the maintenance and repair of various commercial types of landing equipment, including landing legs, shock absorbers, tail-wheel units, brakes, and tires. "Airscrews (Part I)" deals with the maintenance and repair of the de Havilland controllable-pitch airscrews and hydromatic airscrews.

ELECTRICAL CIRCUITS AND MACHINERY. Volume I. Direct Currents. By F. W. Hehre and G. T. Harness. John Wiley and Sons, New York, 1940. 513 pages, illustrated, 9 by 6 inches, cloth, $4.50. Volume one of a two-volume treatment of electric circuits and machinery offered as a successor to the textbook with that title written by Morecroft and Hehre in 1933. Like its predecessor, it is intended as an introductory text for students of electrical engineering and a general text for others. Contains a chapter on electronics.

ELECTRICAL ENGINEERING LABORATORY EXPERIMENTS. By C. W. Ricker and C. E. Tucker. Fourth edition. McGraw-Hill Book Company, New York and London, 1940. 458 pages, diagrams, etc., 9 by 6 inches, cloth, $3.00. Revised and expanded, this edition of a well-known guide includes 70 experiments, with accounts of theory and procedure.

FRENCH-ENGLISH SCIENCE DICTIONARY. For Students in Agricultural, Biological and Physical Sciences. By L. De Vries. McGraw-Hill Book Company, New York, 1940. 546 pages, 7 by 5 inches, fabrikoid, $5.00. Contains 45,000 scientific terms with the English equivalents. While intended to meet the needs of students of agriculture, biology, and physics, it should be useful to students and translators in any field of science.

GEOMAGNETISM. By S. Chapman and J. Bartels. Oxford University Press, New York; Clarendon Press, Oxford, England, 1940. Two volumes, 1049 pages, diagrams, etc., 9½ by 6½ inches, cloth, $18.00. Aims to provide an account of present knowledge for workers in geomagnetism, cosmic-ray physics, geophysical prospecting, and radio communication. Volume I gives a detailed description of the observed facts of geomagnetism and the ways in which they are measured, together with brief accounts of lunar and solar motions, the properties of the sun's atmosphere, solar eruptions, the aurora, the earth's upper atmosphere, and magnetic prospecting. Volume II discusses the analysis and synthesis of geomagnetic data and the physical theories which attempt to explain the facts. Bibliography.

GRAPHISCHE METHODEN ZUR LÖSUNG VON WECHSELSTROMPROBLEMEN. By A. von Brunn. Benno Schwabe and Company, Verlag, Basel, Switzerland, 1938. 243 pages, diagrams, etc., 10 by 6½ inches, cloth, 18 Swiss fr. Graphical methods for the solution of a-c problems are presented in a comprehensive manner. After discussing the fundamental theory and vectorial representation of the physical elements of electric circuits, the author develops the general methods of graphical calculation and many specific adaptations. Bibliography and list of symbols.

Transactions

Preprint of Technical Papers Comprising Pages 643–89 of the 1940 Volume

A Decade of Progress in the Use of Electronic Tubes

Part I—In the Field of Communication*

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THE dependency of the art of communication on the science of electronics is so great as to make a review of progress in electronics almost of necessity a review of the field of communications itself. While it is true that the early forms of telephone and radio communication advanced to a degree without the use of electronic devices as we know them today, the recognition of the vacuum tube as an amplifier and generator of high-frequency alternating currents in the years just preceding the first World War marked a turning point in the development of the communication art. From that day to this the progress of electronics and communications has gone hand in hand. The need of the communications engineer for new electronic tools has kept him continually urging the electronics engineer to improve old devices and to originate new ones, and each time the efforts of the latter have been rewarded with success, the fruits of his work have been immediately applied to produce new and more startling miracles of long-distance communication.

Because of the close relationship of electronics and communications it is necessary in reviewing the progress of the last decade to keep in mind that it is progress in electronics and not in communications which is our theme. It will be necessary to survey the trends in communications during the period under review, but then it will be necessary to ask to what extent the progress which has been made is due to advances in the electronic field and what advances in the electronic devices themselves have laid the foundation of this progress. There has been no attempt made to make this review comprehensive in the sense that it include all items of progress which are of individual interest. To do so would make it merely a catalog of these many advances and an index to the periodical literature of the subject. Rather the object has been to trace the most significant trends of development in the various fields and to emphasize those lines of advance which appear to be most closely related to the general direction of progress in the several fields of electrical communication.

The Trend in Radio—to Ultrashort Waves

The history of radio has seen a continual demand for expansion of the usable region of the frequency spectrum. Because the number of available communication channels is limited it has been necessary to ration the frequency spectrum by governmental regulation and international agreement among the various users and classes of service. Existing services, most of which are experiencing a continual expansion, have completely absorbed the allocations in the intermediate and short-wave band and leave nowhere to place new services but in the ultrashort-wave region above 30 megacycles. Not only are the new services forced to the ultrahigh frequencies by congestion at the longer waves, but in some cases they are themselves of such a nature that an adequate number of channels with the necessary band width can be obtained only at the high frequencies. Television and wide-band frequency modulation are cases in point. A band width of over four megacycles is required to transmit a modern high definition television image. Frequency-modulation systems at present proposed require a 150-kilocycle band. Radio relay systems for these same services will require band widths at least as great and can obviously be accommodated only in the ultrashort-wave region. The development of these and other wide-band services is therefore dependent on satisfactory means for working at ultrahigh frequencies.

Another reason for the current interest in ultrashort waves is that new services are developing making use of their unique transmission properties. Their very shortness makes practical the construction of directive antenna systems and this can be more easily accomplished the shorter the waves. Directivity, which of course can be applied only in the case of point-to-point services, greatly reduces the power requirements on the transmitter. For broadcast services the problem of interference between stations is simplified because the transmission of ultrashort waves is approximately limited to line-of-sight paths. To relate their propagation exactly to line of sight as has been frequently done in recent years is an oversimplification of the problem but it is probably true that the ultrashort waves will find few applications for ranges beyond 100 miles and that interference need not be feared beyond a few hundred miles at most.

In the very front of this field, in the range of centimeter waves, that is above 300 megacycles, the directive possibilities of ultrashort-wave systems become particularly marked. Commercial applications in this region are as yet few, but may be expected to increase rapidly in the future. As examples of the unique type of problem capable of solution only by the use of centimeter-wave technique may be cited the development of the absolute altimeter to measure the height of an airplane over the terrain by the reflection of radio waves[6] and a 40-centimeter airplane blind-landing system.[7]

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* A report prepared for the AIEE joint subcommittee on electronics: H. M. Turner, *chairman*; W. R. Brownlee, J. H. Cox, J. W. Dawson, T. F. Gray, S. B. Ingram, D. C. Prince, Joseph Slepian, Thomas Spooner, W. C. White, and T. A. Worcester. Part II appears on succeeding pages.

1. For all numbered references, see list at end of paper.

The Trend in Television—to Electronic Television

Television is an art which has developed almost entirely within the last 15 years. In no field is the close relationship between communications and electronics better illustrated than here. All modern systems of television depend on the modulation of a carrier frequency wave by a video signal. This video signal is derived by scanning the picture in a series of horizontal lines, the amplitude of the video signal varying with the brightness of the individual picture element traversed by the scanning beam. The transmission of the modulated carrier is a radio problem in which the principal difficulties to be overcome are those related to the wide band required for a high-definition picture and to the high frequencies assigned for television transmission. At the receiver, demodulation and a second scanning process synchronized with the first are required to reconstruct the picture. The earlier systems of television used mechanical scanning methods at both transmitter and receiver. These mechanical scanning methods had numerous disadvantages. They called for rapidly rotating mechanical elements, perforated disks, lens disks, drums bearing mirrors, and numerous other devices of a mechano-optical nature. It is inherently more difficult to synchronize two rapidly rotating mechanical systems than two electrical circuits on account of the inertia of the mechanical parts. It was hard to get sufficient optical efficiency either for satisfactory studio technique at the transmitter or a sufficiently bright image at the receiver. All these difficulties were magnified when the progress of the art called for the production of a high-definition picture, the mechanical problems because a higher scanning speed was required, the optical difficulties because the light available was proportional to the area of the scanning spot and high definition meant a smaller spot. A solution was sought in electronic television. It was found first at the receiver, for the cathode-ray tube which had been used for some time as a laboratory tool had all the elements of an electronic scanning device for a television receiver and needed only to be adapted and improved for the purpose. For the transmitter, however, completely new devices had to be invented and they came in the form of the Iconoscope, the image dissector, and later modifications of these. Today electronic methods of scanning have replaced mechanical methods practically universally at the transmitter although it is as yet too early to say that some place may not be retained for mechanical systems, for example in the scanning of film. At the receiver electronic methods are also most generally used, the Scophony system[61] being the outstanding example of a mechanical scanning method still successfully holding a place for itself.

The Trend in Telephony—to Broad-Band Carrier Systems

Electronic devices have played a major part in the field of long-distance telephone transmission for many years. In local circuits the attenuation is small enough so that no amplification between the transmitter and receiver is necessary to counteract it, but in all long-distance circuits attenuations are so great that without the vacuum-tube amplifier, or telephone repeater as it is called, communication would be impossible. The earlier systems were voice-frequency systems in which one pair of conductors was used to carry each conversation. The advantages of carrier systems in which one pair of conductors could carry several frequency channels each modulated with its own voice current were early recognized. Such systems generally carrying three speech channels have been in use for 20 years or more. The total frequency band transmitted in these earlier systems was however limited to about 24 kilocycles. Within the last decade tremendous impetus has been given to the development of broad-band carrier systems where the frequency band transmitted may be as high as several thousand kilocycles.

There are two general types of broad band carrier systems.[8–10] There are those in which, by the addition of repeaters and terminal equipment, the carrying capacity of existing conductors both cable and open wire can be greatly increased.[11–14] These systems in general will accommodate from 12 to 16 channels per pair and utilize carrier frequencies up to 145 kilocycles. They are extremely important from an economic standpoint since they permit great economy in the amount of plant required to accommodate an increase in traffic when existing facilities are fully utilized. Then there are the very broad-band coaxial-conductor systems.[15,16] The circuit in this case consists of two concentric conductors separated by small dielectric spacers. Such systems are capable of transmitting exceedingly high frequencies with a maximum degree of shielding from outside interference. Their importance lies not only in their ability to transmit as many as several hundred telephone conversations simultaneously, but also in the fact that they present the only practical means at present in prospect for setting up wire transmission systems capable of transmitting high definition images in television broadcasting networks.[17] The detailed discussion of broad-band carrier systems is outside the scope of this paper. What does concern us here is the problem of amplification which must be accomplished by electronic means. In the cable carrier system attenuations run as high as 4 decibels per mile, in the coaxial system 8 decibels at two megacycles. If we envision 1,000 miles of coaxial circuit the attenuation which has to be compensated by amplification amounts to 8,000 decibels. This represents a total power amplification between terminals of 10^{800}. The requirements on the amplifiers of such a system are obviously very stringent. They must have a high degree of stability so that the power level at the terminals shall be constant, they must be linear so that the intermodulation products which would produce interference with one voice channel by another shall be negligible, and they must be capable of transmitting a wide band of frequencies. Such requirements can be met only by the stabilized-feed-back amplifier[74] which is an electronic circuit development of the highest order of importance. Without this solution of the amplifier problem broad-band carrier systems as we know them today would be impractical.

While considering carrier telephone systems we should pause to note one of the losses of electronics as a contender for supremacy in the telephone transmission field. Copper-oxide modulators and demodulators have in general proved superior from the standpoint of compactness, economy, and ease of maintenance to the vacuum-tube circuits formerly used for this purpose.[18]

Progress in Electronic Devices

So far consideration has been given to the trend of progress in the several major divisions of the communications field and it has been shown how electronics has played an important role in contributing to this progress. The remainder of the paper will be devoted to a review of progress more specifically in the electronic devices themselves. In considering these it will be convenient to divide the devices into several broad classes: those depending primarily on thermionic emission

for their operation, those depending on secondary and photoelectric emission and the new science of electron optics, and those based on the phenomena of gas discharges. Finally a few of the most fundamental electronic circuit developments will be described.

Thermionic Devices

The extension of radio into the ultrahigh-frequency portion of the spectrum has been paralleled by a corresponding growth of interest in the development of vacuum-tube devices for use at these frequencies. Those which have found most general use up to the present time are modifications of the familiar three-element or negative-grid vacuum tube designed particularly to fill the requirements of ultrahigh-frequency operation.[19–21] Major development efforts have proceeded in two directions; toward the generation of relatively small amounts of radio-frequency power at higher and higher frequencies, attempting to extend the useful portion of the radio spectrum into the region of the centimeter waves, and toward an increase in the usable range of power at more moderate frequencies in the lower parts of the ultrashort-wave region where television and frequency modulation have brought a commercial demand for radio transmitters. In the former class the frequency limit has been pushed up to 1,800 megacycles; in the latter water-cooled power amplifiers capable of power outputs of approximately 10 kw at 100 megacycles are now commercially available.

The tendency of negative-grid tubes to produce unwanted oscillations due to the feedback of power from the output to the input circuits makes the problem of producing amplifiers at the ultrahigh frequencies more difficult than that of producing satisfactory oscillators. Methods of neutralization which can be used at lower frequencies to prevent these oscillations from occurring become inadequate at the higher frequencies because of the inherent difficulties of circuit technique. The problem has been solved by the construction of special push-pull pentodes containing two tube structures within one envelope.[22,23] With such tubes, stable amplifiers with power outputs of 10 watts at 250 megacycles and some measurable amplification as high as 500 megacycles have been constructed.

Negative-grid tubes are used both as oscillators and amplifiers. Two other devices, both by their nature incapable of amplification but interesting as oscillators because their power-generating capacity exceeds that of negative-grid tubes in the centimeter-wave region, have received considerable attention.[24–26] These are the positive-grid or Barkhausen oscillator and the magnetron. Of these the latter has received the greater attention. Magnetrons depend for their operation on the curvature of the path of the electrons as they move under the influence of the electrostatic field between a filament and a surrounding cylindrical anode placed in a homogeneous magnetic field along the axis. Two general modes of oscillation exist. In the first the static negative-resistance characteristic of the tube is utilized. Operating in this mode magnetrons have been used to produce power outputs of as high as 450 watts at 46 centimeters.[27,28] Efficiencies in the range from 30 to 60 per cent have been reported. While this is considerably better than has been obtained with the negative-grid triode, there are difficulties of frequency stability and modulation with magnetrons, and these together with the additional complication of the equipment required to supply the magnetic field make them rather poor competitors of negative-grid tubes at these frequencies. The second type of magnetron oscillation is one in which the transit time of the electrons is approximately equal to the period of the radio-frequency output.[29] Operating in this manner the magnetron has established the record for ultrahigh-frequency wave generation at 61,000 megacycles corresponding to a wave length of only 4.9 millimeters.[30]

For the conventional negative-grid triode the maximum power-handling capacity has been shown to vary inversely as the square of the maximum frequency at which the tube is designed to operate[19] so that some new principle must be called into play if significantly greater power outputs are to be realized in the centimeter-wave region. Very recently tubes operating on such fundamentally new principles have occupied a great deal of attention by research workers and show promise of giving performance considerably better than that yielded by negative-grid tubes both with respect to power output in the centimeter-wave region and to their maximum frequency of operation. They differ in their principles from conventional tubes in that the radio-frequency output is taken from the electron stream by induction in an anode element which is not the same as that which collects the current and which therefore does not need to dissipate the d-c power. The variations in electron density capable of inducing these radio-frequency currents are produced in two different ways. In the inductive output tube[31] the conduction current is modulated by a cathode grid structure exactly as in the ordinary triode. In the "velocity modulation" tube[32] or in the so-called "klystron"[33] the principle of velocity variation is used. A stream of electrons accelerated from a cathode passes through two grids between which a radio-frequency signal is applied. This signal retards or accelerates the electrons according to the phase of the cycle at which they happen to pass the grid giving rise to velocity variation of the beam which then passes through a field-free "drift space" in which the faster electrons catch up to the slower ones. A bunching or conduction current variation of the beam is thus produced and renders it capable of generating radio-frequency currents in the output electrodes by induction. Tubes of this design overcome two limitations inherent in the negative-grid type. Higher efficiencies may be attained because the output electrode is not called upon to dissipate the tube losses and in the case of velocity-variation tubes transit time through the radio-frequency input section of the device is much less than in triodes since the electrons are moving with high velocity when they enter this space instead of having to accelerate from zero velocity. This greatly reduces "active grid loss", that is, the increase of grid driving power required as the operating frequency is increased which is directly due to the transit time becoming comparable in magnitude with the radio-frequency period and which is the fundamental limiting factor in the high-frequency operation of negative grid tubes. In contrast to the magnetron, velocity-variation tubes are well suited to operation as radio-frequency amplifiers. Experimental data on performance reported in the literature are meager as yet but operation at frequencies as high as 6,000 megacycles (five centimeters) and oscillator power outputs of 500 watts at 750 megacycles have been reported.[1]

Space will not permit the mention of many detailed improvements in the general field of thermionic vacuum tubes, but some reference should be made to the application of electron optics to thermionic devices in the beam power tube.[33] In this tube the electron stream, which is confined to move in beams by accurately lined up grids and by electrostatic deflecting plates, produces a space-charge potential minimum in the neighborhood of the plate which suppresses secondary emission just as the retarding field of the suppressor grid does in the ordinary pentode. Such tubes have re-

ceived wide acceptance as power amplifiers on account of the high efficiency obtainable with them.

Wide-band amplifiers of the type required in television receivers and in broad-band carrier systems require tubes with a high ratio of transconductance to interelectrode capacitance. Recently developed tubes for these systems have shown considerable advances in this respect[39,40] and in view of the increasing importance of broad band systems, further advances can be anticipated along this line.

Devices Based on Secondary Emission, Photoelectric Emission, and Electron Optics

The devices which we will consider in this section are largely a group whose development has been brought about by the needs of the new art of electronic television. They have been made possible by the great advances made in the underlying science of electron optics, and by putting to work the phenomenon of secondary emission. The knowledge and application of the laws of electron optics have progressed to the point where beams of electrons can be focused and directed in accord with well-defined and well-understood laws. Electron images can be projected in space by electron lenses which consist of electric fields set up by suitably disposed electrodes at the proper electrical potentials or by magnetic fields from the appropriate current-carrying coils.

The basic phenomena of secondary emission have been known for many years. Their effect in modifying the characteristics of vacuum tubes was also well known, the third grid in the ordinary pentode being introduced specifically for the purpose of suppressing secondary electron emission from the plate. It was not however until recently that it was demonstrated that since one electron impinging on a suitable surface with appropriate energy has the ability to release more than one secondary electron, it is possible to build electronic amplifying devices based on the phenomenon of secondary emission. These devices are called secondary emission multipliers.[41,42,57] In general they consist of a number of successive electrodes whose surfaces have been suitably treated to give them a high secondary emission ratio and which are maintained at sufficient potential difference to give an optimum over-all multiplication to the device. If under these conditions a secondary emission ratio of m prevails, the multiplication in k stages is m^k. Values of secondary emission ratio in present-day multipliers are typically in the neighborhood of four and the number of stages varies up to 16. Total over-all amplifications of several billion have been reported.[43] The limiting output is determined by power dissipation in the last stage and defocusing of the electron beam due to space charge. Multipliers can be associated with various types of input. When applied to a tube with a photoelectric input, multipliers can readily be produced with sensitivities as great as 30 milliamperes per lumen or greater.[44]

One advantage of such multipliers over the combination of a photoelectric cell and a thermionic amplifier is that no coupling resistor is required between the photoelectric-cell output and the first stage of amplification. Thermal noise in this resistor is therefore eliminated, and for this reason the photoelectric multiplier is capable of operating at much lower levels of illumination than the photoelectric cell with thermionic amplification.[41,46] As described below, multipliers can be associated directly with the output of television pickup devices. Finally, secondary-emission multiplication applied to the output of an ordinary thermionic vacuum tube offers attractive possibilities in the field of wide-band amplification since circuit problems could be greatly simplified if an amplifying device were available capable of giving a greatly increased gain per stage. The multiplier can do this and has the further important property that its amplification is essentially independent of frequency up to many megacycles where transit time becomes a limiting factor. One interesting commercial tube in which one stage of secondary electron multiplication is added to an ordinary tetrode, has a transconductance of 14,000 micromhos.[46]

The electron optical problems of multiplier design are worthy of special attention because of the ingenious methods which have been devised for their solution. Earlier multipliers used magnetic focusing to assure that all the electrons originating on one stage were suitably collected on the succeeding one. Present-day multipliers are generally of the electrostatic type, the electrodes being so shaped that the equivalent focusing action is obtained. The problem of determining electron trajectories in ordinary multiplier structures is too complex to admit of ready mathematical solution. Electrolytic tank models for determining electric fields in complicated structures and mechanical models for determining electron trajectories have proved invaluable design tools.[43,44] In the latter method metal spheres rolling on a stretched rubber membrane whose slope simulates the electric fields of the tube elements can be shown to trace out the trajectories with a highly practical degree of accuracy.

In electronic television systems four types of pickup tubes are today in common use. The first is the image dissector.[45–48] In this tube the visual image is focused on a photoelectric surface. The photoelectrons emitted are focused by means of an axial magnetic field in the plane of the scanning aperture. This whole image is then moved back and forth across this stationary scanning aperture, the image thus being "dissected." Since the aperture must be minute for a high-definition television picture, the current is very small and passes immediately into an electrostatic electron multiplier for amplification. The output from the last stage of this multiplier is the video signal.

The second pickup tube is the Iconoscope.[58,59–64] The essential element of this tube is the mosaic plate consisting of minute islands of photoemissive substance backed by a thin insulating layer of mica the reverse side of which is covered with a conducting coating. This layer forms the output electrode of the device and to it the elements of the mosaic are capacitively coupled. The optical image is focused on the mosaic. Photoelectrons are emitted from the elements causing them to assume a potential which is dependent on the intensity of the light falling upon them. The mosaic is scanned by an electron beam from an electron gun. This electron beam impinging on the surface under conditions in which the secondary emission ratio is greater than one recharges the element to a definite equilibrium potential and the variations in the recharging current required constitute the video signal which is transmitted to the output circuit through the capacity of the mosaic.

The Iconoscope has the important advantage over the image dissector that its elements act to store charge during at least a portion of the scanning time and this stored charge is then swept away quickly during the traverse of the scanning beam. This gives it a considerably greater sensitivity than the image dissector and makes it suitable for taking scenes under many conditions of illumination where the image dissector is inadequate. Balanced against this is the presence in the Iconoscope output of a spurious signal or "dark spot" arising from the redistribution of photoelectrons and of secondary electrons from the

scanning spot over the whole mosaic surface. This spurious signal must be balanced out by the electrical insertion of a compensating signal from a special electrical network. The image dissector also has an advantage in being a directly coupled device the output of which contains information as to the general level of illumination of the picture. The Iconoscope being capacitively coupled gives information only as to variations in illumination, and its output must therefore be continuously monitored to adjust for changes in background illumination as well as for the dark-spot signal just mentioned. At present the Iconoscope type of camera appears to have most general applicability on account of its greater sensitivity but the simplicity of operation of the image dissector gives it a field of use in special cases, for example in pickup from motion-picture film where adequate levels of illumination are easily obtained.

Sensitive as the Iconoscope is on account of its charge-storing property, still more sensitive pickup devices are urgently required by television techniques. Tests show that the charge storage in the mosaic is not greater than five or ten per cent what would be expected under ideal charge-storage conditions, being low because the field which attracts the photoelectrons from the mosaic is small and because only a fraction of the secondary emission current reaches the anode. The super-emitron[64] or its American counterpart the image Iconoscope[65] increase this low efficiency. In these tubes the photoelectric surface is separated from the mosaic, an electron image of the electrons emanating from the former being focused on the latter by means of an electron lens. This mosaic is then scanned as in the Iconoscope. This arrangement enables two gains to be made. A more efficient photoemissive surface can be produced and the photoelectrons may be drawn away from it under conditions of voltage saturation. An over-all gain in sensitivity of about ten times over the Iconoscope has been achieved in practical tubes of this type. They are used to some extent in commercial television pickups particularly under low outdoor conditions of illumination.

Another interesting pickup tube, the "orthicon," has recently been described.[66] It differs from the Iconoscope in that the mosaic is scanned by a beam of low velocity electrons. The photoelectrons leave the surface under voltage saturation conditions giving the tube an over-all high efficiency and making the light response linear. Since the energy of the scanning electrons is low, secondary emission plays little or no part in the operation of the device and the level of the spurious signal is low. Such devices appear to offer promise but problems of focusing a low-velocity beam are formidable and the definition of pictures produced with such tubes do not at present compare favorably with those obtained with the Iconoscope.

For the picture tube in television receivers the conventional cathode-ray oscilloscope tube needed only to be adapted, although many detailed improvements have been required. Electron guns for producing high-current electron beams of accurate focus have been developed.[68] Great progress has been made in the production and use of fluorescent materials.[69] Much of the current development effort is directed at the production of tubes with a sufficiently bright image to enable optical projection onto a large screen.[70] Tubes for this purpose with electron-beam energies as high as 80 kv are under laboratory investigation.[69]

Gas-Discharge Devices

In communication systems gas-filled tubes have found most general use as rectifiers to provide d-c power from a-c supplies or as relay devices in control and signaling systems. Use in circuits carrying the communication signals themselves has proved impractical because of the noise inherent in the gas discharge itself and various proposals for gas-filled amplifying devices have so far proved impractical on this account.

In radiobroadcast transmitters, mercury-vapor rectifiers have largely replaced rotating machines for providing d-c supplies. Mercury-vapor rectifiers have been found to give efficient service with a minimum of maintenance for all outputs up to 20 kv and 100 amperes.

Thyratrons or gas-filled rectifiers which contain a grid to control the starting of the discharge are also becoming widely used in rectifiers for battery charging in telephone central offices. By utilizing grid control in such tubes, regulated rectifiers can be built which automatically adjust the charging rate of the battery in such a way as to hold its terminal voltage constant as load and line voltages vary.[71,72] This condition makes for long battery life and also eliminates the maintenance required by manually adjusted chargers.

In control and signaling systems one type of gas-filled device, the cold-cathode tube,[73] appears to offer prospect of extensive use. In its simplest form it consists of a gas discharge tube containing a cathode, an anode, and an auxiliary electrode. The passage of a small amount of current of the order of one microampere to this auxiliary electrode will control the starting of the anode current which can then be as large as 10 to 100 milliamperes in existing types. The tube thus functions as an extremely sensitive relay. Dissimilarity of cathode and anode can be used to provide a rectification property. In recent years cold-cathode tubes have been extensively applied in four-party selective-ringing circuits for the selective signaling of telephone subscribers on party lines.

Electronic-Circuit Developments

The importance of the stabilized-feedback amplifier in wide-band carrier telephone systems has been brought out. The principle of such amplifiers is basically very simple.[74] A portion of the output is fed back to the amplifier input usually through an attenuating network in such a manner as exactly to oppose the input signal. This reduces the over-all gain of the amplifier and also reduces noise and distortion usually in the same proportion. With modern high-amplification-constant vacuum tubes the decrease in gain can be readily restored and the net result is an amplifier which is superlatively better than the simple amplifier without feedback. The first major advantage of such amplifiers is the linearity of their characteristics. In carrier systems this is important since intermodulation which causes interference between the various speech channels can be practically eliminated. To obtain this same result without the use of stabilized feedback would require the use of vacuum tubes of much larger power ratings operated over a small portion of their characteristics with a consequently greatly reduced efficiency. The second advantage of the negative-feed-back amplifier is its stability. When the amount of feedback is large it can be shown that the over-all amplification depends only on the characteristics of the feed-back circuit and is practically independent of the amplifying circuit. Since the feed-back circuit contains only fixed circuit elements and no vacuum tubes the over-all amplification becomes independent of variations in tube characteristics and supply voltages. This stability is essential in a carrier system which has many repeaters in tandem if the total amplification between terminals is to remain constant. The third advantage is the ease with which the over-all gain

and the gain frequency characteristic of the amplifier can be controlled. These are functions only of the feedback circuit characteristic which can be given any desired shape by the introduction of appropriately designed equalizing networks. In carrier systems the attenuation-frequency characteristic of the line and the variations in attenuation-frequency characteristic with temperature can thus be almost exactly compensated by adjusting the gain-frequency characteristic of the repeaters.

A great amount of technical interest and commercial activity is currently being devoted to a new form of radio-broadcasting known as wide-band frequency modulation.[75,76] It is as yet too early to say what the ultimate development of this system will be, but its most enthusiastic advocates foresee the obsolescence of the present system operating within the broadcast band in the neighborhood of one megacycle and the development of a new ultrahigh-frequency system operating on the principles of frequency modulation. In conventional radio-telephone systems the amplitude of the carrier wave is modulated by the audio frequency. In the proposed system the frequency of the carrier is caused to vary back and forth over a frequency band approximately 150 kilocycles in width, the instantaneous deviation of the frequency from the mean being proportional to the instantaneous amplitude of the modulating audio signal. This system has several interesting features as compared with the existing low-frequency amplitude-modulation broadcasting. Natural atmospheric noise is inherently low in the ultrahigh-frequency region of the radio spectrum. Interference from automobile ignition systems, on the other hand, is more severe than at broadcast frequencies. The characteristics of the proposed frequency-modulation system are such that the radio-frequency interference-to-signal ratio may be higher without noticeable interference with the program than is the case with amplitude modulation. The same characteristics of the system which make this true are effective in reducing interference between stations on the same frequency. It is possible with frequency modulation to transmit programs of high fidelity without unduly high expenditures of power at the transmitter but this is done at the expense of using a wider frequency channel.

The extension of high-frequency practice to the centimeter wave region has called for new circuit techniques. As the frequency is increased the lumped inductances and capacities of the resonant circuits decrease and the distributed constants of the connecting leads play a continually greater part in the circuit performance. In the ultrahigh-frequency region and particularly at wave lengths less than one meter, it becomes convenient to do away with the lumped circuit constants altogether and to use instead the resonant properties of transmission lines of either the parallel wire or coaxial types.[77] Such circuits are readily adjustable, convenient to work with, and the mathematical theory of their properties is well understood. At still higher frequencies even transmission-line circuits become impractical but at this point the resonant properties of conducting cavities can be exploited to advantage. It was demonstrated about four years ago[79] that a cavity whose boundary is a good conductor is capable of sustained electrical oscillations at certain characteristic frequencies determined by its geometry and that such cavities may be used advantageously as circuit elements associated either with sources or sinks of electromagnetic wave power. In some recent electronic devices, for example the velocity-modulation tubes and klystrons mentioned above, this principle has been invoked. The tube elements themselves have in effect been set directly into the walls of such resonant cavities.[78]

Closely related to the phenomena of resonant cavities is the propagation of electromagnetic waves through hollow metal tubes or wave guides.[79–84] For simple geometrical shapes the theory of this form of electromagnetic wave propagation is well established.[80] Propagation can take place only when the wave length is less than some critical value which is of the same order of magnitude as the diameter of the conductor. The method is therefore limited to the ultrahigh frequencies. Attenuations even at these extremely high frequencies can be made comparable with those of ordinary coaxial cable at the lower frequencies so that at the moment wave guides appear to offer considerable promise in future wide-band ultrahigh-frequency communication systems. The end of a wave guide may be flared out into a highly directive electromagnetic horn which may be used either as a radiator or receiver of ultrahigh-frequency waves. The resulting power gains are comparable with or even greater than those of the more conventional directive antenna arrays now in general use.[85–8] The rapid development of the understanding of the transmission properties of ultrashort waves in waveguide systems has provided a further impetus for the development of electronic devices capable of generating and amplifying these ultrahigh frequencies.

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No attempt has been made to make the bibliography comprehensive. The aim has been to include papers of most fundamental importance and, where they are available, those of a review nature which will assist the reader who wishes to go more fully into the developments of any particular field. Preference has been given to the literature printed in the English language since it has been felt that this will be of most use to the average reader. In so doing it has not been intended to slight the much excellent work on electronics and communications which has been carried on abroad.

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A Decade of Progress in the Use of Electronic Tubes

Part II—In Other Than the Field of Communication*

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Synopsis: The past ten years include nearly the whole period during which electronic tubes have been used outside the communication field. The types of tubes used in this field may be classified into groups, each having properties that make it valuable in certain phases of industry or in specific applications. The references are grouped according to nature of application and represent a selected group chosen by careful elimination from several thousand.

IN comparison with the communication field, the use of electronic devices in other industry has played an entirely different role. In communication in general and in radio in particular, tubes and tube developments have been basic to most improvements. They have been truly called the "heart" of nearly all radio apparatus. In other industry, however, they have in general had to supplant other methods and to compete in highly developed fields of electrical engineering.

The use of tubes in the noncommunication field has passed through several broad phases. At first they were looked upon with a certain amount of mistrust as being rather fragile playthings entirely unsuited for the severe conditions encountered in the industrial field. Next, as a result of the increased popular interest in science and the optimism of the late 20s, they became "wonder" devices and their wide use in nearly every electrical field was freely predicted.

Within the past few years, a more realistic viewpoint has prevailed and much solid progress has been made. It is realized that there is no magic in an electron tube, and the tube must either accomplish something that cannot be done by any other means or make its own way against competition solely on the basis of what it can do for less cost than existing methods.

Scope of This Review

The last decade includes the greater part of tube activity in this field, but reference is necessarily made occasionally to earlier work to clarify or to complete the picture.

Electrons are now known to play such an active part in so many devices that, in the interest of brevity, certain devices are not included in this review. These omissions are neon lights as well as other gaseous light sources, ultraviolet tubes, X-ray tubes, pumped mercury-arc tanks, iron-wire ballast tubes, mercury and vacuum switches, and uses in phonographs and talking moving pictures. This review is also limited to American references in the interest of brevity.

Due to the activity in this field and the relatively long period covered, only a small fraction of the available references are included. Those included were chosen on the basis of availability, general nature of treatment of subject, and their use of further references.

The emphasis in this review has been placed mostly on tube applications rather than the tubes themselves. This has been done because of the wider interest in applications and because the review must be kept to a reasonable length. The references to tube design have been included only when they were important from the viewpoint of new applications or unless similar tubes were not used in communication.

Arrangement of References

In general the references are classified under headings similar to those employed by the AIEE in indexing its TRANSACTIONS in past years.

Factors Favoring the Use of Tubes in Industry

In competing with rotating equipment, the use of tubes eliminates noise, vibration, and the need of special foundations.

The ability to amplify from very low input levels both in high-vacuum and gas-content tubes makes them unique electrical devices. Their amplification can also be made continuously variable rather than step-by-step.

Tubes provide cycle-by-cycle and fractional-cycle control.

Tubes in combination with such devices as thermocouples, microphones, photoelectric cells, and movable capacitance plates permit electrical response to temperature, sound, light, and motion. Therefore, they extend control operations to variations in sensory response.

Tubes also find ready application where they extend certain factors to extreme limits. Timing to very short intervals, response to extremely small electrical quantities, and control from very small movements are examples of this.

They operate relatively independent of frequency in comparison with most other electrical devices.

Factors Retarding the Use of Tubes in Industry

The relatively high cost of tubes in combination with the fact that they are renewable items has retarded their application.

Their mode of operation and application has not been so commonly understood as other electrical devices.

Considerable engineering knowledge and effort are often required to work out a new application successfully and in some cases the expense of this apparently cannot be justified from the viewpoint of available business.

A General Summary of Types of Tubes

The following comments are based on tube types and applications outside the communication field.

HIGH-VACUUM DIODES

These tubes are inherently rectifiers only and are suitable for use where high frequencies are involved. Their use is also limited in general to currents of about an ampere. They are suitable, however, for voltages up to the hundreds of thousands.

The early applications of this type of tube were for the purpose of obtaining high voltage (25 to 150 kv) for smoke and dust precipitation as well as high-voltage cable testing by power companies. This

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use has continued and grown to some extent. They also find a wide variety of application, but in limited quantities, in laboratories for high-voltage, low-current, d-c power supplies.

High-Vacuum Tubes With Control Grid or Grids

This class of tubes involves one or more control electrodes; their chief functions are as amplifiers and oscillators. They range in ratings from less than a watt to over 100 kw.

There are probably hundreds of thousands of these tubes in daily operation in a bewildering variety of circuits. By far the big majority of them are radio-receiving-tube types used in oscillating and amplifying circuits. In some cases, requirements of power output or a special operating condition has dictated special types. Automatic train control, high-frequency therapeutic oscillators, and low-grid-current amplifier tubes are examples of such special designs. There are many others.

The literature contains hundreds of articles on special applications of this class of tube and thousands of references are made to their use in the literature.

Hot-Cathode Gas-Filled Diodes

This class of tube is utilized for rectification of heavier currents at lower frequencies and voltages than the high-vacuum type. Gas-filled tubes have a relatively low and constant voltage drop in comparison with high-vacuum tubes.

There is one field where the great majority of tubes of this type are used and that is for low-voltage battery charging. Most of these are tungsten filament, argon-filled tubes for currents under ten amperes, and for direct voltages under 125.

Another group of rectifier tubes of this class utilizes mercury vapor and is suitable for voltages up to about 20,000. Although the great majority of such tubes are used for d-c power supply of radio transmitters, some are used for high-voltage testing and to supply direct current for high-frequency tube oscillators.

Similar tubes are also employed in rectifiers to supply power at the lower standard voltages—125, 250, 500, and 650—to replace power formerly obtained from a d-c Edison system or private generating plant.

Hot-Cathode Gas-Filled Grid-Controlled Tubes—Thyratrons

The control action of this type differs from the high-vacuum type in that only the start of the discharge is controllable. They are particularly suitable for controlling currents of a few amperes from a-c circuits. Their ability to control by cycles of the a-c supply leads to a number of valuable applications.

One of the earliest commercial applications for this type of tube was for the control of the illumination from incandescent lamps used in theaters and decorative lighting. In this application they functioned as controlled rectifiers to supply a variable direct current to saturation reactors. These latter functioned as variable reactors in series with the groups of lamps.

Within the past few years, applications have fallen largely into certain classes:

(*a*). Rectifiers to supply variable voltage or current from an a-c source of supply. This combination is employed to control d-c motors, field excitation of generators, and various electromagnetic devices.

(*b*). Inverters to supply either constant or variable-frequency a-c power (up to a limit of a few hundred cycles) from a d-c supply. As a variation of this the same general principle may be used for frequency changing.

(*c*). The use of a pair of tubes connected "back-to-back" so that in combination they pass alternating current. This gives a circuit element that not only acts as a contactor but by phase control of the grid voltage permits variation of the current passed. These tubes are so used in some welding control circuits where too large currents are not involved.

During recent years there has been a trend toward the use of inert gases, such as argon, neon, or xenon, to replace mercury vapor. This gives this class of tubes a freedom from ambient temperature effects that are sometimes troublesome with the use of mercury-vapor tubes. They are, however, not usable for peak inverse voltages up in the thousands as in the case of mercury vapor tubes. For small tubes to handle fractions of an ampere, the inert gas content also allows operation as an inverter up to thousands of cycles.

Cold-Cathode Glow-Discharge Tubes

These are particularly applicable where filament operating power is not available and where ample control voltage can be employed. These tubes are often equipped with control electrodes. They are characterized by a higher voltage drop than the hot-cathode or pool type of gas-content tube. Also the current-carrying capacities are limited to a fraction of an ampere average current except that currents up to a hundred amperes or more can be carried for very short periods of time.

The two-electrode form has a number of applications that may be classified as follows:

(*a*). As a discharge tube to break down at some abnormally high voltage and thus act as a circuit protective device.

(*b*). As a voltage regulating device to place across a circuit. This use results from the characteristic of such a tube, with proper design, to pass a wide range of currents with a nearly constant voltage.

(*c*). As a negative-resistance element to generate oscillations by the relaxation circuit principle.

(*d*). As a rectifier based on the dissimilarity of the two electrodes.

(*e*). To produce light in accordance with the pulses of current through the tube. The light produced may be extremely intense for a very short time as for stroboscopic work or modulated in accordance with a variable current intensity or frequency.

When one or more control electrodes are added, the characteristics of a relay are gained. The applications listed above are retained and in some cases their scope extended. To date the three-electrode form has largely found its usefulness in the communication field but has wide relay possibilities in industry as it becomes better known and further developed.

Photoelectric Tube

In industry the photoelectric tube is performing many functions not possible by other means. In addition it is becoming an important agent in eliminating routine human effort. In combination with an amplifying tube, it is finding its place in applications where the eye and the hand are needed but not the brain.

During the past ten years, photoelectric-tube applications in great numbers have been made and, due to their apparent news value, widely publicized. Development of the photoelectric tubes themselves has been along the lines of smaller size, greater sensitivity, selective response in the spectrum, and novel mechanical designs for special applications. Lowered cost has also been helpful in extending their use.

Their applications may be grouped into three general classes:

(*a*). Applications in which a light beam, when interrupted or established, actuates a photoelectric relay. Examples of this are sorting, counting, door opening, hole detection, alarm systems, safety devices, and miscellaneous control jobs in industry.

(*b*). Applications where the tube and its accessories are actuated by variation in the amount of light falling upon it. Examples of this are smoke detection, check on turbidity of solutions, photometry and radiation measurement.

(*c*). Applications utilizing the difference in response of photoelectric tubes to light from different parts of the spectrum either directly or by the addition of filters.

Photoelectric tubes may be grouped according to the combination of features they employ. These classifications are:

(*a*). High-vacuum or gas-filled to increase their sensitivity.

(*b*). Nature of photoemissive surface which controls sensitivity and response to different parts of spectrum including the ultraviolet.

(*c*). Design and composition of bulb to transmit or restrict light flux from different parts of the spectrum to the photoemissive surface.

(*d*). Variations in mechanical design to adapt the photoelectric tube to special uses involving size, nature of base and direction, and degree of solid angle from which radiation reaches the photoemissive surface.

Existing photoelectric tubes have various combinations of these features.

Photovoltaic cells and selenium cells have not been considered within the scope of this review.

Pool Tubes—Ignitrons

The outstanding characteristic of the pool cathode is its ability to pass very heavy currents—thousands of amperes. The addition of the ignitor gives the pool tube control characteristics. By phase control, voltage and current regulation are obtained and, by cycle control, short-time switching functions.

For a considerable number of years, preceding about 1933, the sealed-off pool type of tube had been slowly experiencing a decline in usefulness. Its chief applications were battery charging and high-voltage rectification for series arc lamps for street lighting. These were not growing applications. Then two new developments appeared which changed this picture completely. One was the ignitron and the other was the sealed steel envelope. The first solved the starting problem and gave the pool type the equivalent of grid control. The latter made large tubes and water-cooling practical and the tubes more acceptable to industry.

Since 1933 the use of pool tubes has grown steadily. Most of this growth has been in the welding control field where the tube's ability to carry very heavy peak currents has been an all important factor. The use of the sealed-off steel envelope ignitron for power conversion rectifiers for outputs between 75 and 350 kw has begun and appears to be a promising field.

Cathode-Ray Tubes

In industry the use of a fine beam of electrons to produce and control a light spot on a fluorescent screen for oscillographic purposes is most common. These tubes can also be used for various forms of indicators.

For many years cathode-ray-tube oscillographs were considered as laboratory devices only but now they are commonly employed by electrical engineers and are necessities for many measurement problems. A better understanding of them, together with better-designed equipment and lowered cost, have been the chief contributions.

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Measurements at Radio Frequencies

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IT IS interesting to recall that this art is less than a century old[1] and that the early experimenters[2] actually worked in the frequency range now called "hyper frequencies."

The same basic principles are used at power frequencies and radio frequencies in the measurement art but the different techniques and nomenclatures often obscure this fact. These differences have arisen because the magnitudes of the fundamental quantities usually are widely separated. As the frequency is increased, the circuit usually changes markedly[3] since elements which are negligible at one frequency often become important in the new range. Size, design, and required accuracy also affect measurement problems.

It is the purpose of this paper to discuss the more common measurement problems at radio frequencies and to give a résumé of the status of this rapidly growing art.

Measurements of Voltage

The primary standards of voltage at radio frequencies are actually the usual d-c standards, and measurements are made by means of transfer instruments. The most popular instrument is the vacuum-tube voltmeter[4] which is available in forms ranging from the simple diode rectifier to a multitube inverse-feedback amplifier. All forms have the following characteristics in common: high input resistance, 0.25 to 10 megohms; low input capacitance, 1.5 to 30 micromicrofarads; response proportional to peak or average value, depending upon design; flat frequency response over the range for which they are designed, and they require a power supply. Because some forms of this instrument are so reliable and versatile, it is really no problem to measure radio-frequency voltages for a wide variety of conditions. The problem of obtaining a voltage measurement without affecting the voltage being measured is more common at radio frequencies than it is at power frequencies. The acorn-type vacuum tube is generally useful when this problem is encountered because of its small size and good electrical characteristics. Even under conditions which require that the small capacitance of this tube be compensated for, good measurements have been obtained. In fact, with proper technique, the acorn diode has given satisfactory operation at 300 megacycles per second. Conditions sometimes require that the diode voltmeter be built into the circuit[5] to avoid the errors which would result from moving even such a small device from one part of the circuit to another.

The vacuum thermocouple[6] is also a useful transfer device at radio frequencies because of the following characteristics: small frequency corrections, one calibrated on direct current has a correction less than one per cent at 100 megacycles per second; response to effective value regardless of wave shape; small size; and it is a passive network, primarily resistive. In addition, there is the cathode-ray tube which is rapidly gaining favor because it gives information as to wave form and frequency as well as magnitude. At present, it is much more expensive and more difficult to use than the other devices.

The radio engineer is often concerned with the microvolt, but none of these instruments is sufficiently sensitive to measure such small voltages so indirect means are employed to effect these measurements. A common way is by comparison with a voltage obtained by attenuating a voltage of the order of one volt by known amounts.[7] Another way to obtain microvolts is to generate them with a microvolt generator or second harmonic generator.[8] Figure 1 shows one form of the microvolt generator, and figure 2 is a schematic diagram of it. It is a full-wave rectifier so connected that the usually unwanted ripple current is used to generate a known voltage across the known impedance, Z. It depends upon the fact that if the tube characteristics are square law, the only output will be at twice the frequency of the input voltage and the peak value of this output

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1. For all numbered references, see list at end of paper.

current will be equal to the change in direct current in the plate circuit. When the tube characteristics depart from the square law, higher-order even harmonic currents are generated. It has been found practical to use the sixth harmonic. The essential fact is that no fundamental or odd harmonics are present and the radio-frequency current is indicated by a d-c microammeter.

When special problems arise, such as measuring 0.1 microvolt, which cannot be readily solved by either of the methods described, it is usually wise to refer to the work of Faraday, Maxwell, Hertz, and other pioneers. A mutual-inductance attenuator based on Maxwell's formula[9] and tested at high level was found easy to construct, test, and use to obtain voltages of the order of 0.1 microvolt at 40 megacycles per second.

The problem of measuring high voltages at radio frequencies is usually solved by using some form of multiplier with a moderate-voltage instrument as it is at power frequencies. The problem of designing the multiplier has no satisfactory general solution, but when capacitance dividers cannot be used, a tuned circuit or a quarter-wave section of transmission line may provide the solution.

The problem of inventing a practical standard of voltage at radio frequencies is fascinating and tantalizing. The phenomenon of resonance potential[10] in gases appears to have promise. A tube in which this phenomenon was observed is shown in figure 3. It consists of an anode and cathode sealed into a tube along with a drop of mercury and a coating of zinc sulphide. The anode is like the grid of an ordinary vacuum tube so that many of the electrons will go beyond it to strike mercury atoms. Those electrons having an acceleration of 4.87 volts cause radiation at a wave length of 2,537 angstrom units and this radiation is made visible by the fluorescence of the zinc sulphide. The problem remaining is to get precise correlation between the impressed voltage and the resonance potential. There must be a way to harness the electron.

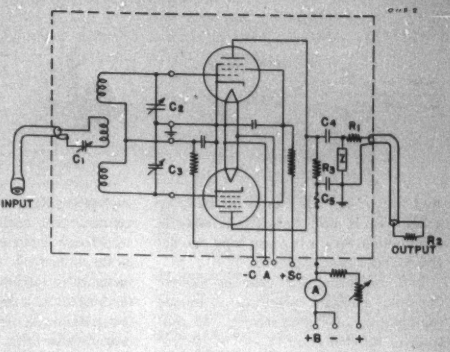

Figure 2. Schematic diagram of microvolt generator

Measurement of Current

The primary standard of current at radio frequencies is the oscillating-ring type of electrodynamic ammeter,[11] figure 4. Although unconventional in its method of indication, the oscillating-ring type of electrodynamic ammeter is simple. It is essentially a metal ring, free to rotate about a diameter, and immersed in an electromagnetic field produced by the current being measured. The field tends to orient the plane of the ring parallel to the flux lines with a torque proportional to the mean square current and to the small angular displacements of the ring's plane from this torque node. Therefore, if the ring is mechanically displaced and then released, it oscillates about the torque node, until damping brings it to rest, with a frequency of torsional oscillation proportional to the rms current. To obtain the value of a current, then, instead of noting the deflection of a pointer on a scale, the observer determines the mechanical frequency, F_m, of oscillation of the ring.

The actual measurement required for each determination is that of time, a fundamental measurement which can be made with great accuracy. Mathematically, the high-frequency current is given by the equation,

$$I = \left(\frac{2\pi\sqrt{JL}}{m}\right) F_m$$

where J, L, and m, are the ring's moment of inertia, inductance, and coefficient of mutual inductance with the exciter and are calculable from measurements of lengths and mass which need be made but once for the instrument. Since the fundamental measurements of length, mass, and time suffice for the determination of current in this instrument, it is a primary standard. That the required measurements of length, mass, and time can be made, and the necessary computation carried out, with accuracy, has been demonstrated by checking several different designs of vibrating-ring electrodynamic instruments against thermocouple ammeters at frequencies below the thermal error range of the latter.

As to structural details of this type of instrument, the exciter or current-carrying circuit, in whose field the ring is placed, is not restricted to any one form. For example, a single circular loop has been found useful for low currents and a single toroidal turn (figure 4) for large currents. In any case, its form does not require high inductance, nor does its function require an energy-consuming heating effect. Neither is large shunt capacitance, inherent in the temperature equalizing terminals of thermocouples, at all necessary.

The support for the ring may be a simple fiber suspension, or jeweled bearing for greater sturdiness.

The determination of the mechanical frequency of the ring's oscillation may be done quite closely by an observer with a

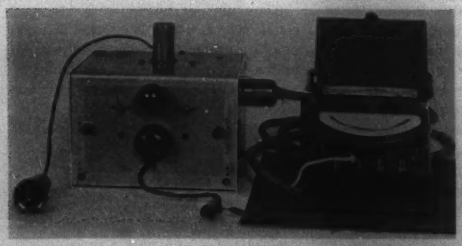

Figure 1. Microvolt generator with indicator

Figure 3. Critical-voltage tube

stop watch, or with greater precision by a light beam and photoelectric relay in conjunction with a two-pen tape chronograph and a time standard.

The oscillating-ring type of electrodynamic ammeter possesses a unique combination of characteristics. In contrast to the deflection types[12] of electrodynamic instruments, its impedance is independent of current, and it is not subject to loss of precision nor to limitation on maximum current by a cramped scale. As in other electrodynamic ammeters for high frequency, the effect upon its indication, produced by raising the frequency of the current, is calculable and small. In contrast to the effect in thermal ammeters, it decreases with increasing frequency. This follows from the fact that whereas thermal ammeters depend upon effective resistance which continues to increase with frequency, electrodynamic instruments depend upon flux linkages or inductance which approaches a fixed limit as frequency is raised. For example, in a conventional five-ampere thermocouple, the change in indication was calculated to be 1.6 per cent between 0.5 and 5.0 megacycles, and over 40 per cent between 5 and 50 megacycles; whereas in one electrodynamic instrument used, the corresponding figures were 0.77 per cent between 0.5 and 5 megacycles, and only 0.25 per cent between 5 and 50 megacycles.

A secondary standard of current at high frequencies, like one at power frequencies, should be capable of insertion in a circuit without seriously affecting the operation of either the circuit or the instrument. Furthermore, essentially all the radio-frequency current led to the "high" terminal should traverse the actuating element, and no indication should be had from strong surrounding fields. It is also desirable that high-frequency error in the actuating element be minimized.

The design of a low-impedance thermocouple-type ammeter indicates the methods applied to meet these requirements. In this low-impedance design, the actuating element or heater is a thin flat ribbon doubled back on itself with a thin mica separator between its inner surfaces. In order to preserve the advantages of minimum inductance and negligible stray fields inherent in this type of heater, its supporting studs are made short and concentric. The center stud, having its external end flattened and drilled to serve as the ammeter's "high" terminal, visible in figure 5, intrudes through an insulating bushing in a small shallow cup so that it makes contact with one flat end of the heater whose other end, opposite the mica separator, is mounted on the center of the cup's bottom. The cup, shown removed from the ammeter in figure 6, is recessed in the ammeter's back plate which itself serves as the external "low" terminal, seen in figure 5. The shielding effect of this concentric "low" terminal is continued about the miniature d-c instrument by the small contiguous metallic case and scale plate.

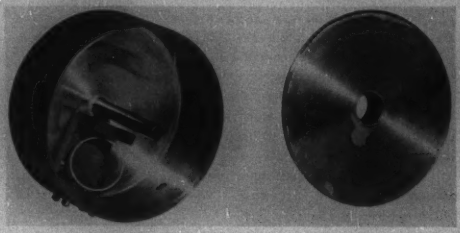

Figure 4. High-frequency electrodynamic ammeter

The effect on performance at high frequencies, which the above features of design have produced in the low-impedance thermocouple-type ammeters, is indicated by the results of comparative tests such as those described below.

For example, two conventional "high-frequency design" thermocouple ammeters when placed in series, read alike at 32 megacycles, one per cent different at 42 megacycles, and three per cent different at 52 megacycles; but these same instruments when individually placed in series with the low-impedance type instrument, with the latter in the "low" side of the circuit, each read the same as the low-impedance ammeter.

A further indication of the low impedance of this type of instrument is given by the fact that when applied as a series resonance indicator in a conventional wavemeter circuit, it allowed extension of the top frequency from about 150 to 360 megacycles at the same time permitting the use of a larger inductance loop. The wavemeter[13] smoothly covered a band from 160 to 360 megacycles, with a capacitor of 25 micromicrofarads maximum capacitance and an inductance comprising slightly more than one turn one inch in diameter in addition to the capacitor leads. The inductance of the instrument is 0.005 microhenry.

The effectiveness of its shielding has been demonstrated in a test in which a number of thermocouple-type ammeters, including both the low-impedance and conventional types, were placed directly in radio-frequency fields. Between 15 and 90 megacycles, the ammeters were placed within one-quarter inch of the tank coil of a 50-watt oscillator, and between 260 and 380 megacycles they were placed in the maximum field of the tank lines of a line-controlled 15-watt oscillator. Although conventional-design ammeters during these exposures, with no current actually applied, gave readings ranging from zero at lower frequencies to more than full scale at higher frequencies, the low-impedance type instruments under the same conditions uniformly maintained a reading of zero.

Thus, when the low-impedance thermocouple-type ammeter is inserted in a circuit, it introduces a minimum of reaction on the circuit, remains unaffected by surrounding fields, and indicates no more nor less than the current entering its "high" terminal. In addition to the demonstration of these characteristics prerequisite in a secondary standard of high-frequency current, further tests have shown that skin-effect error at high frequencies in the doubled-ribbon heater has been greatly reduced below that found in the solid-wire type of heater.

The concepts of Faraday are particularly helpful in problems of measuring current at high frequencies, because when high-frequency currents of any size flow, the fact that the energy is in the fields becomes apparent. For example, men standing six to eight feet away from a ten-kilowatt oscillator operating at 75 mega-

cycles have felt their ankles get warm. This approach to a current-measuring problem leads to correct application of available instruments because the way high-frequency currents divide in a particular circuit becomes reasonable when the fields are considered. When a spacer is thought of as a dielectric medium rather than as an insulator, the "mysterious" loss of current in a circuit becomes an expected occurrence.

Measurements of Frequency

A primary standard of frequency is an oscillator whose rate is substantially constant when determined by counting the number of oscillations and dividing it by the time taken to produce them. The unit of frequency is, therefore, based on the standard second which is 1/86,400 of the mean solar day or 1/86,164.100 of the sidereal day. The National Bureau of Standards maintains several primary standards of frequency and makes some of them available for general use by means of standard frequency transmissions over station WWV, Beltsville, Md. Many laboratories maintain primary standards of frequency by using the WWV standard frequency transmissions and the United States Naval Observatory time signal[14] transmissions to check them. The counting of radio-frequency oscillations may be accomplished by means of a combination of electronic counter circuits and a mechanical counter. The multivibrator[15] or relaxation oscillator is commonly used for the electronic counter and a synchronous-motor clock for the mechanical counter. Rates constant to one part in ten million are commonly obtained by means of quartz-crystal-controlled oscillators operating at 100,000 cycles per second.

In many cases, a signal from the oscillator or transmitter whose frequency is to be determined can be brought to the primary standard and the measurement made by direct comparison. When this is not practical and an accuracy of 0.1 per cent is acceptable, the common absorption-type wavemeter consisting of an inductor and a capacitor connected in series can be used. The operation of this device depends upon the following relation between frequency, inductance, and capacitance:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

When greater accuracy is required, some form of the heterodyne wavemeter may be used. The heterodyne wavemeter is a calibrated oscillator which can be tuned to the frequency of the unknown signal with great accuracy by one of the beat note methods. When a quartz-crystal-controlled oscillator is used to check the calibration of the heterodyne oscillator, an accuracy of 0.001 per cent can be obtained.

The problem of measuring higher and higher frequencies stays with us as the art progresses. In most cases, the first need is a suitable receiver for the unknown signal and the problem remaining is to set a high-frequency oscillator accurately on a harmonic of the standard. For example, adjust a 1,000-kc crystal to the tenth harmonic of the 100,000-cycles-per-second standard, then set a 10,000-kc crystal oscillator on the tenth harmonic of the 1,000-kc oscillator. This process can be carried as far as necessary to provide guide posts in the upper frequency spectra.

Since frequency can be measured so accurately, it is highly desirable to be able to use it as the indicator when measuring other quantities. For example, an excellent way to measure small changes of capacitance[16] is to put the capacitor in an oscillating circuit so that these changes cause changes in frequency which can be monitored continuously and accurately.

Measurements of Power Factor and Dielectric Constant of Materials

It is as important to know the power factor and dielectric constant of an insulating material used in a radio transmitter as it is to know the power factor of a load on a power line. The power factor of a material is the cosine of the angle whose cotangent is the ratio of conductance to susceptance in the sample when it is used as the main dielectric in a two-electrode capacitor. This is based on representing the sample by a pure resistance in parallel with a pure capacitance. It may also be represented by a resistance in series with a capacitance and then the power factor is the cosine of the angle whose cotangent is the ratio of resistance to reactance.

Power-factor standards can be made of disks of pure, clear fused quartz because the power factor is 0.0002 from 1 to 3,000 megacycles per second. The bases of this statement are a determination at 3,000 megacycles by W. C. Hahn, engineering general department, the work of Von Lothar Rohde[17] at 200 and 500 megacycles, and the work of this laboratory.

There are many ways[18] of measuring the power factor of a material at frequencies less than one megacycle per second. Some of the circuits available are: parallel bridge, series bridge, resistance variation, substitution, and reactance variation.

At frequencies above one megacycle, the reactance-variation[19] type of circuit has been popular. This popularity probably resulted from the fact that power factor is determined by measuring capacitances, changes of capacitance, and ratios of voltages. Variable capacitance of known value is easier to obtain than variable resistance at frequencies above one megacycle. The procedure is to measure the width of the resonance curve for a certain ratio of voltage at resonance to voltage off resonance with the sample capacitor tuning the resonant circuit and repeat this with an air capacitor in place of the sample. These data are sufficient for two separate circuit-resistance determinations and, therefore, for the effect of the sample on the circuit. Since the measurement of power factor is a resistance measurement, the following factors in addition to those in the measuring equipment are important: the size and shape of the sample; the size, shape, and material of the electrodes; and the method of applying the electrodes to the sample. The size and shape of the sample are major determining factors of the capacitance. If this capacitance is made small compared to the inherent capacitance of the measuring circuit, it will obviously become difficult to determine the effect of inserting the sample. On the other hand, if it is made large, its reactance will approach that of the residual inductance in the measuring equipment and will cause resonance effects and consequent inconsistent operation. The size and shape of

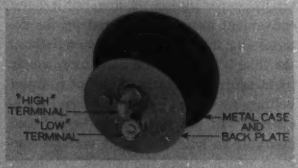

Figure 5. Low-impedance thermocouple ammeter (rear)

Figure 6. Low-impedance thermocouple ammeter (front)

the electrodes also affect the capacitance, but the effective resistance of the electrodes is often the more important factor.

Because there are so many possible sources of error, it is good to have a clear fused-quartz standard sample to test the over-all operation of any power-factor measuring equipment.

The dielectric constant of a material is the ratio of the capacitance of a pair of electrodes with the dielectric between them to their capacitance for the same spacing in a vacuum. It is necessary to choose the electrode geometry properly[30] to allow accurate determination of the dielectric constant when the sample size is fixed. The capacitance of the sample is usually a by-product of the power-factor measurement procedure.

Measurements of Impedance

One way to determine impedance is to measure the current through and the voltage across the unknown impedance and calculate the ratio of E to I. Even at power frequencies, it is not convenient to use this method and at radio frequencies it is seldom convenient to use. One reason for this is that one-inch leads are the same part of a wave length at 63.36 megacycles per second as one-mile leads are at 1,000 cycles per second. It is hard to overemphasize the need for short leads from the measuring equipment to the unknown impedance.

In addition to requiring short leads, the problems which have arisen frequently since the advent of television have required that the measuring equipment be portable where portable means that the user can carry it up an antenna tower and use it at the top. An instrument for this service in the 40 to 70 megacycles per second frequency range is shown in figure 7 and a schematic diagram is shown in figure 8. It will be noticed that provision has been made to obtain short leads. At the same time, the measuring circuit was shielded from the oscillator and from external fields by placing it in a separate metal compartment, by providing Faraday screens between the oscillator coil and one coupling coil and between the other coupling coil and the measuring circuit coil, and by using a common ground.

Figure 7. Portable impedance measuring instrument

The measuring circuit is a coil and a capacitor so arranged that either balanced or single-ended impedances can be measured by the reactance-variation method. The parallel tuned circuit has been so arranged that the unknown can be connected in series with the coil and consequently low values of impedance can be measured. The usual parallel connection of the unknown is also provided for high values of the unknown. The procedure is to determine the circuit constants with and without the unknown connected in terms of capacitance, change of capacitance, and voltage ratios. The differences between the two resulting sets of susceptance and conductance values are the constants of the unknown impedance.

This instrument was used in the installation of the transmission lines and antenna of General Electric television station W2XB in band 3 (66 to 72 megacycles).

It is often necessary to measure the inherent inductance in low-value resistors. One way to measure these small inductances is to use the microvolt generator.

The procedure is to insert a resistor, R_1, as Z and measure the current, i_1, which causes a certain output at frequency, f_1; replace R_1 by a different resistor, R_2, and find the current which causes the same output; repeat this procedure at another frequency, f_2, and solve the resulting simultaneous equations:

$$i_1\sqrt{R_1^2+(2\pi f_1 L_1)^2}=i_1\sqrt{R_2^2+(2\pi f_1 L_2)^2}$$

$$i_1'\sqrt{R_1^2+(2\pi f_2 L_1)^2}=i_2'\sqrt{R_2^2+(2\pi f_2 L_2)^2}$$

In a particular case, a two-ohm and a ten-ohm resistor were used at 25 and at 40 megacycles. The inductance of the two-ohm resistor was 0.016×10^{-6} henry. The impedance of the two-ohm resistor is, therefore, 3.20 ohms at 25 megacycles and the necessity for determining inherent inductance in low-value resistors is evident.

Measurements of Transmission Line Characteristics

In television transmitting systems as in other radio transmitting systems, it is usually impractical to locate the transmitter unit adjacent to the antenna. A transmission line is employed to connect these parts, and for the wide-frequency-band operation needed in television communication, the transmission line must have quite definite characteristics.

Physically such a transmission line usually consists of straight sections of concentric tubes with spaced low-loss beads for insulation. Sections are joined at corners by means of junction boxes and the inner conductor is supported in long vertical runs by means of an anchor joint. To secure proper performance of the transmission line, it is necessary to compensate for the electrical disturbances produced by these junction boxes and anchor joints. It is also necessary to match the antenna circuit to the transmission line

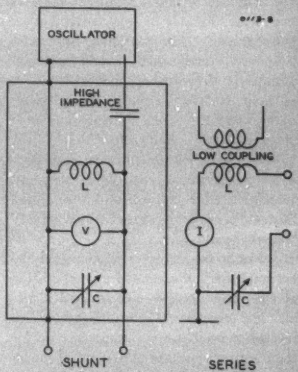

Figure 8. Schematic diagram of measuring instrument

much more closely than was commonly practiced in communication or broadcast transmitter systems. For these reasons, it is desirable to measure the characteristic impedance of the line and to determine its frequency characteristic with compensating elements added at the required positions.

The reactance-variation type impedance-measuring instrument already described can be used to measure the characteristic impedance of the line, but it is not convenient to use this instrument for determining the frequency characteristic of the line. This may be done more easily by measuring the ratio of output to input voltage over the operating range of frequency. In practice, it has been found desirable to hold the input voltage constant which makes the output voltmeter indication proportional to the ratio wanted.

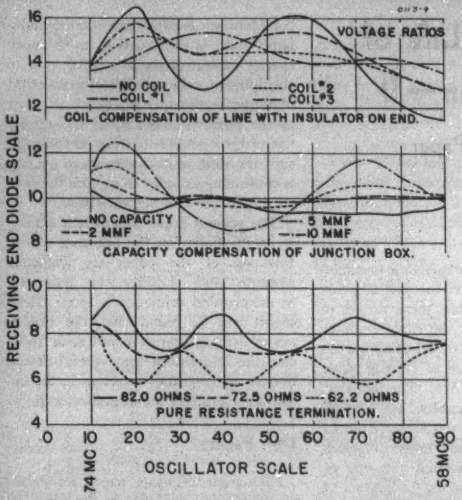

Figure 9. Experimental voltage-ratio curves

It is necessary that the ratio of output to input voltage remain practically constant over the operating-frequency range and desirable that it remain so over a wider range to give a safety factor. The information given in plots of voltage ratio versus frequency is shown in figure 9. The lowest set of curves shows that resistance terminations can be readily identified as lower or higher than characteristic impedance of the line. The middle set shows how changes of capacity at a junction box caused marked and easily recognized changes in the ratio curves also. The top set demonstrates the case of coil compensation.

When this method of measuring transmission-line characteristics is used, it is desirable to start with a short section and to add junction boxes, other sections, and anchor joints one at a time. If several things are added at once, the voltage-ratio curves become difficult to interpret; but if one thing is added at a time, the curves are as easy to interpret as those shown. A mathematical treatment of these relations is in the literature.[21]

That complete transmission characteristics over wide frequency ranges can be secured by properly using a pair of diode voltmeters is encouraging.

Conclusions

How basic principles are used in making measurements at radio frequencies has been shown in a number of cases.

Something of the range of the subject has been suggested by the diode voltmeter and the "critical voltage" tube.

A primary standard of current at high frequencies has been described.

A new low-impedance thermocouple ammeter has been presented.

Clear fused quartz has been proposed as a standard of power factor in the 1 to 3,000 megacycle-per-second frequency range.

A typical technique of making measurements at radio frequencies has been disclosed by the description of the "reactance-variation" method of measuring impedance.

It is hoped that the material presented will prove informative to engineers not directly connected with radio-frequency measurement work as well as to those in it.

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The Dielectric Strength and Life of Impregnated-Paper Insulation—II

The Influence of the Thickness of the Paper

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FELLOW AIEE

THE peculiarly severe conditions imposed by manufacture, transportation, installation, and operation of high-voltage cables have emphasized the importance that full attention be paid to all physical properties of the insulation, especially those relating to permanence of mechanical structure and of high insulating properties. The requirement of wide flexibility is at the root of the present method of applying the paper insulation in spiral tape form in successive layers.

Mechanical flexibility and high dielectric strength do not always go hand in hand. They do so to an astonishing degree in the case of impregnated paper. However, with the available materials it is not always possible to retain at the same time the maximum of flexibility and the maximum of dielectric strength and stability. Consequently in cable design, in order to meet the special requirements of particular cable installations, it is necessary to make such selection of the paper to be used as will ensure the optimum combination of flexibility and dielectric strength. Carefully prepared wood-pulp paper with low content of electrolytic impurity is now used almost exclusively for the type of insulation in question. It is available over fairly wide ranges of density and thickness, as determined largely by experience in manufacture and usage over the past 20 years or more. It is within these ranges of paper structure that the cable engineer finds the possibility of selecting papers for a very wide range of type of cable and conditions of service. The fact that impregnated-paper cables are giving highly satisfactory service for large blocks of power in the highest range of values of voltage is an indication not only of the remarkable insulating properties of this type of insulation, but also of the resourcefulness and persistence of cable engineers in experimental study and manufacturing skill.

In a related paper,[1] the present author has reported the results of a study of the influence of a variation of the density of the paper on dielectric strength as determined in a fixed program of accelerated

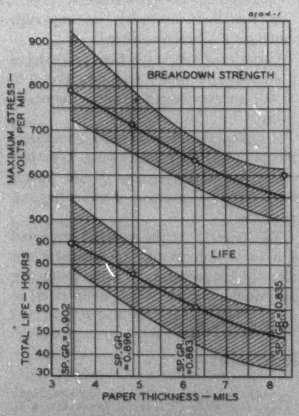

Figure 1. Breakdown strength and life as function of paper thickness

voltage-time tests. The results of the study were at some variance with commonly accepted ideas[2] as to the influence of paper density on dielectric strength. They confirm the suggestion that has been made from time to time[3] that proper consideration must be given to the laminated form of construction, to the open spaces between successive tapes, and to the different values of dielectric constant of impregnated paper and of oil. In view of the positive character of the results and of their possible bearing on cable design, the work on the influence of density is continuing in order to explore the possible influence of other variables.

The present paper describes a similar series of studies on the influence of the thickness of the paper on dielectric strength and stability, as indicated by accelerated voltage-time tests. Here too it will be found that the results are of definite character and again indicate the importance that careful attention be given to the variations in the internal structure of the insulation wall.

The Papers

High-grade cellulose paper for cable manufacture is available in the range of thickness 0.0035 to 0.008 inch (3.5 to 8 mils, 0.0089 to 0.02025 centimeter). For the present studies four thicknesses of approximately 0.0035, 0.0048, 0.0063, and 0.00835 inch were used. The papers were supplied by a well-known manufacturer in the form of tapes one inch wide. It was intended that the density of the paper structure be the same for each thickness. As measured, however, the density of the 8-mil paper fell slightly below the others (see table I). We refer to the papers briefly as having nominal thicknesses 3, 5, 6, and 8 mils respectively.

The Test Specimens

The test specimens were made by wrapping the paper tapes on smooth brass tubes with 33⅓ per cent and 66⅔ per cent overlay with a butt spacing of the tapes of approximately 1/64 inch (0.00397 centimeter). The number of layers of each thickness of paper was so chosen as to give approximately the same over-all thickness of all test specimens. (See table I.)

Nine identical specimens were constructed from each thickness of paper. They were dried and impregnated in groups of three. All specimens were impregnated with a light oil as used for oil-filled cables by American manufacturers.

Further details as to the measuring and guard electrodes, reinforced ends, etc., of the test specimens, of the physical characteristics of the oil, and of the methods of drying and impregnation will be found in earlier papers.[4]

Paper 40-104, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE summer convention, Swampscott, Mass., June 24-28, 1940. Manuscript submitted April 5, 1940; made available for preprinting May 6, 1940.

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This research, carried out in the laboratories of the School of Engineering of The Johns Hopkins University is a project of the Engineering Foundation with the sponsorship of the AIEE. Grateful acknowledgment is made of the support and advice frequently furnished by both these bodies, and particularly by members of the advisory committee appointed by the AIEE to follow the course of the work. Cordial thanks are also extended to the Union Mills Paper Company, The Sun Oil Company, the Locke Insulator Corporation, and to the Insulated Power Cable Engineers Association for material and other forms of assistance furnished. Special thanks are due Research Assistant C. O. Newman, to whose skill and devotion much of the success of the work is due.

1. For all numbered references, see list at end of paper.

Experimental Method

All tests were made on single specimens immersed in the impregnating oil in a bath enclosed in a thermally insulated box with automatic temperature control.[5] The air pressure in the test box was that of the atmosphere. The temperature for all tests was 40 degrees centigrade.

Life and Breakdown Tests. The accelerated voltage-time tests started at a voltage to give an average stress of 400 volts per mil on the specimen and the test voltage was increased by 3.12 per cent every four hours, thus giving a geometric increase such as to bring the stress to 700 volts per mil within three days. Under this program the range of life of all specimens tested was from two to four days.

Power Factor and Capacitance. Power factor and capacitance were measured over the range 100 to 400 volts per mil on a high-voltage Schering bridge[5] at the beginning of the voltage-time test and at 12-hour intervals.

Conductance. The long-time d-c conductance of the dry paper specimen was measured at 1,500 volts and 105 degrees centigrade before impregnation, and of the impregnated specimen at 60 degrees centigrade immediately following impregnation.

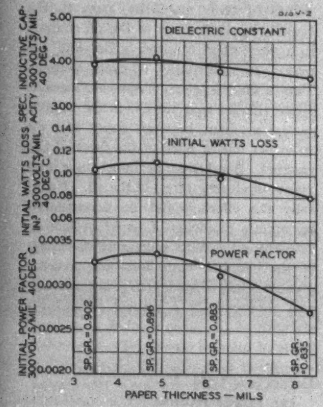
DIELECTRIC CONSTANT
INITIAL WATTS LOSS
POWER FACTOR
INITIAL POWER FACTOR 300 VOLTS/MIL 40 DEG C
INITIAL WATTS LOSS SPEC. IND. CAP. 300 VOLTS/MIL 40 DEG C
INDUCTIVE CAPACITY 300 VOLTS/MIL 40 DEG C
SP. GR. = 0.902
SP. GR. = 0.899
SP. GR. = 0.883
SP. GR. = 0.835
PAPER THICKNESS — MILS

Figure 2. Dielectric constant, dielectric loss, and power factor as function of paper thickness

Experimental Results

The results of the accelerated voltage-time and breakdown tests on the three-mil paper are given in table I. They are typical of the results on the other thicknesses of paper, for which the average values only are given in the table. Using the average values of breakdown stress, as given in table I, the results on breakdown strength and accelerated voltage-time and other electrical properties are plotted in figures 1 and 2. The shaded areas represent the extreme limits of the spread of the test values. The average spread is substantially lower as seen in table I.

The results indicate that with increasing thickness of the paper, there are marked variations in all the electrical quantities, as well as the values of breakdown stress and life.

Breakdown Strength and Life. Both these quantities decrease with increasing thickness of paper, over the range studied. (See figure 1.) This similarity of behavior is a necessary consequence of the type of accelerated voltage-time test. Since the life run begins with a stress of 400 volts per mil, it happens that the percentage change in over-all duration of time (life to breakdown) is greater than that of voltage. The decrease in the average values of breakdown stress is from 788 to 602 volts per mil. This indicates a decrease in breakdown strength of something more than 25 per cent as between the three-mil and the eight-mil papers. This decrease would have been about 28 per cent if the specific gravity of the eight-mil paper had had the same value as that of the other papers. Discussion of these results and a probable explanation will be found in a later paragraph.

Dielectric Constant. Over the range of thickness studied there is a small decrease in the value of dielectric constant (see figure 2). This is apparently due to the slight decrease in density with increasing paper thickness. Corrected[1] for this variation, the value of the dielectric constant is very closely the same for all thicknesses.

Dielectric Loss and Power Factor. Both these quantities show a noticeable decrease in value with increasing paper thickness. Of the total change in power factor approximately 40 per cent may be attributed to the change in paper density.[1] The fraction of the total change

Table I. Accelerated Voltage-Time Tests—Influence of Paper Thickness

Specimen	Number Layers	Paper Thickness	Density J.H.U.	Oil:Paper Ratio by Weight	Breakdown (Volts Per Mil)	Hours at Maximum	Total Hours	Power Factor at 300 Volts Per Mil	Dielectric Loss (W/in.³ at 300 Volts Per Mil)	Capacitance (μμf, at 300 Volts Per Mil)
34-A	23	0.00353			770	3.8	87.8	0.00318	0.1010	608
34-B	23	0.00351			770	2.6	86.6	0.00312	0.979	602
34-C	23	0.00344			830	3.0	95.0	0.00318	0.1015	624
35-A	23	0.00342			722	2.2	78.2	0.00332	0.1030	611
35-B	23	0.00345			745	3.1	83.1	0.00338	0.1069	616
35-C	23	0.00344			745	2.7	82.7	0.00334	0.1072	627
36-A	23	0.00350			795	1.5	89.5	0.00331	0.1068	620
36-B	23	0.00337			928	1.2	109.2	0.00327	0.1057	644
36-C	23	0.00338			795	2.6	90.6	0.00322	0.1031	636
Average		0.00345	0.902	38.8	788	2.6	89.2	0.00326	0.1038	621
Maximum deviation					17.8%					$K = 3.94$
Average deviation					5.28%					
Specimen 22-24										
Average	(16)	0.00487	0.896	40.2	727	1.48	78.0	0.00336	0.1102	651
Maximum deviation	(16)				17.6%					$K = 4.11$
Average deviation	(16)				5.64%					
Specimen 37-39										
Average	(12)	0.00631	0.883	42.1	633	2.3	61.3	0.00312	0.0969	634
Maximum deviation	(12)				7.26%					$K = 3.82$
Average deviation	(12)				3.95%					
Specimen 40-42										
Average	(10)	0.00835	0.835	49.1	602	1.6	53.6	0.00272	0.0803	550
Maximum deviation	(10)				20.0%					$K = 3.69$
Average deviation	(10)				7.35%					

due to this cause in the case of the loss is approximately 30 per cent. Apparently, therefore, some factor other than density is playing a part in these decreases.

Oil Content. The oil content of the impregnated paper tape alone expressed as the ratio by weight of oil to paper is given in table I. It will be seen that the volume of oil absorbed increased approximately uniformly with increasing thickness of paper from the value 38.8 per cent for the three-mil, to 49.1 per cent for the eight-mil paper. This variation also is accounted for by the variation in paper density.

Type of Breakdown. All specimens were carefully examined after failure as to evidence of its beginning and cause. In the latter half of the work these studies were greatly facilitated by the use of a thyratron tube, relay, and rapid circuit breaker[6] for interruption of the primary circuit of the transformer. The operation of this device is so sensitive and rapid that not only is the usual burning attendant upon breakdown very greatly reduced, but in many cases the circuit is opened before the failure has extended further than two or three layers of paper. Further details of the operation of this equipment are given in the paper already referred to on the influence of the density of the paper on breakdown and life.[1]

Failures took place almost invariably under the central electrode of the test specimen and all failures have been of definitely radial type.

A clear indication of the foregoing studies on density, and of the present studies, is that most of the failures begin in the oil channels between successive turns of paper, most often at the central high-voltage electrode, sometimes in the center of the insulation wall, and in a few cases at the outer electrode. In a number of cases in which the specimen was dissected after the first two or three shots, the incipient failure was found to be confined to two or three layers. At one point the oil in a channel would be found to have become black, the blackening extending a short distance either way along the channel and along the edge of the paper. The next stage would be the puncture of one or perhaps two paper layers, but generally reaching the next oil channel on the same radius. Occasionally longitudinal tracking and tree patterns to adjacent channels were noticed, but these extended only a very short distance, probably because of the relatively thin total wall thickness. Evidence of initial blackening in oil spaces was also invariably noticed at the edges of the small holes in the central tubular conductor and outer lead-foil electrode drilled to facilitate drying and impregnation. However, the failure showed no preference for the edges of these holes. Invariably the central tubular conductor would be blackened under the full spiral length of the oil channel between the tape edges of the first layer, the remainder of the conductor remaining clean and bright.

Altogether the failures seem to be closely similar to those reported by Robinson[7] and Race,[8] both of whom find that the initial carbonization occurs next an electrode. However, several of our specimens have shown evidence that the initial seat of the trouble may be in the center of the insulation wall.

The interrupted failures and behavior described above are best observed in the thinner range of papers (see particularly results of the study of the influence of paper density[1]). In the present tests as the thickness increases, it is more and more difficult to limit the failure to a portion of the wall. Most of the failures above those in the three-mil paper have been through-failures with more pronounced burning, with less tendency to tree patterns and tracking and consequently with greater obscurity of the conditions surrounding initial failure.

Discussion of Results

Breakdown Strength and Life

The most probable explanation of the decrease of breakdown stress and life with increasing thickness of paper is the well-known fact that the breakdown strength of thin oil films decreases with increasing thickness. Our results indicate that the failures always start in the oil films between successive turns of paper tape. J. Sorge[9] reports a decrease of dielectric strength with increasing gap thickness, between approximately parallel planes, for xylol, benzene, and hexane, over a range of thickness 0.2 to 0.7 millimeter (8 to 28 mils). This is just outside our range of oil-channel thicknesses (3.5 to 8.0 mils). However, Sorge's curves are all pointing sharply upward at the lower values of gap. Other authors[10] report similar behavior.

Approximate computations[1] of the values of stress in the oil channels in our results in the increasing order of paper thickness are 1,506, 1,416, 1,170, 1,075 volts effective per mil. Naeher's[11] values for pure liquids and thicker layers mentioned above are from 1,700 to 1,200 volts per mil. His results on transformer oil and for gaps from 0.5 to 3 millimeters show a decrease of from 560 to 400 volts per mil. It will be seen, therefore, that our values are intermediate between those for the pure liquids of Sorge and those of Naeher for transformer oil, which was probably not so highly purified as the oil of our tests. In explanation of the above behavior, I suggest the presence of mobile ions in the oil which are greater in number with increasing thickness of oil channel. These ions, owing to the high values of their mobilities, pass to the radially opposite faces of the oil channel in a very small fraction of one-half the period of alternating 60-cycle voltage. They accumulate at the opposite faces as space charges and thus increase the potential gradient between paper and oil on either one or both of the faces of the channel. Breakdown begins at these high points of electric stress in the oil. Naturally the effect would be accentuated by minute filaments of paper projecting into the oil. With increasing thickness of the channel, more ions are present, greater values of space charge accumulate, and consequently a critical breakdown strength of the oil is reached at a lower value of over-all stress.

Dielectric Loss and Power Factor

These two quantities apparently decrease with increasing thickness of the paper, the former by about 20 per cent and the latter by about 15 per cent. The explanation is not entirely obvious. Only a portion of these decreases is accounted for by the variation in paper density. With increasing paper thickness, there are obviously fewer oil layers between paper tapes. The oil channels, however, apparently do not enter into the matter of loss in any considerable extent; first because the oil channels have the same total thickness for all thicknesses of paper; moreover, the volume of oil is a relatively small fraction of the total volume, and the loss per unit volume in oil is generally substantially less than that in the impregnated paper.

The losses in impregnated paper, qualitatively speaking, should vary in accordance with the laws for a Maxwell layer dielectric. This affords a very much better explanation of the results found. There are fewer oil layers with the thicker tapes and the barrier action to current flow is obviously greater in the thicker tapes. Thus the number of surface layers of charge at the surfaces of separation, the amount of dielectric absorption, and consequently the dielectric loss under alternating stress, are all lowered with increasing thickness of paper.

Summary and Conclusions

1. Accelerated voltage-time tests have been carried out on samples of impregnated-paper insulation with the thickness of the paper tape as a variable. Four thicknesses of nominal values, 3, 5, 6.5, and 8 mils, and all of approximately the same density, were studied. All specimens were impregnated with a very fluid insulating oil.

2. In accelerated voltage-time tests beginning at 400 volts per mil and with geometric increase of voltage at the rate of 3.12 per cent every four hours, the 60-cycle breakdown voltage was found to decrease with increasing paper thickness. Over the range of thickness mentioned, the decrease in breakdown voltage with increase of thickness was about 28 per cent. The decrease in life was approximately 45 per cent.

3. The failures almost invariably start in the oil channels between successive convolutions of the paper tape.

4. The maximum stress in the oil channels at breakdown, as computed from the dielectric constant of the oil, and the measured dielectric constant of the impregnated paper, decreased with increasing thickness over the range studied from 1,506 to 1,075 volts effective per mil. An explanation of this behavior is offered.

5. The dielectric constant of the impregnated paper is approximately constant over the range of thickness studied.

6. Power factor and dielectric loss decrease with increasing paper thickness, the former by about 30 per cent and the latter by about 20 per cent over the range of thickness studied. This behavior is explained qualitatively by the variation in interfacial polarization in accordance with Maxwell's theory.

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Discussion

Discussion will be found in the 1940 annual TRANSACTIONS volume and in the 1940 SUPPLEMENT to ELECTRICAL ENGINEERING—TRANSACTIONS SECTION.

Computation of Accuracy of Current Transformers

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WHILE the general principles of the operation of current transformers have been known for some time, and tests have provided much experimental data, the introduction of high-speed relaying, especially differential protection, required a greater knowledge of current-transformer performance than was necessary previously. It is the purpose of this paper to present a method of calculating the accuracy of current transformers.

Formulas for calculating leakage flux and leakage reactance in power transformers have been available for several years. Some good experimental work showing the effect of leakage on the flux densities of the core of current transformers was done by H. W. Price and C. K. Duff of the University of Toronto, and much study has been devoted to the magnetic properties of iron and other material, but little seems to have been done in applying the formulas of power transformers to current transformers, or in establishing the rules which govern the effect of leakage flux on the accuracy. Most of the information concerning current transformers has been derived by the experimental method of making ratio correction factor and phase-angle tests of models.

However, within recent years, a considerable amount of work and testing has been done at the West Lynn Works of the General Electric Company to obtain reliable information on the exciting currents of various magnetic materials over a wide range of flux density. This information made it possible to check methods of calculating the accuracy. The method of calculation here presented was developed largely on a theoretical basis from the fundamental principles involved making use in so far as possible of the well-established power-transformer formulas and was found to give results in very good agreement with the tested accuracy.

By using the method presented in this paper it becomes possible to calculate current-transformer performance from available experimental data without making and testing models. This makes it possible to design current transformers for specific application, or determine the suitability of an existing design without the cost of overcurrent ratio and phase-angle test. It is also very useful as a tool to the designer, because it enables him to compare several proposed designs, and select the best at less cost than by using experimental models and making tests.

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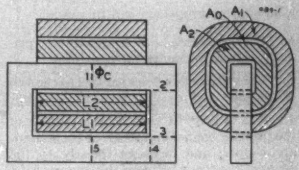

Figure 1

A_1—Area of end of primary winding as shown*
A_0—Area of space between windings as shown*
A_2—Area of end of secondary winding as shown*
L_1—Primary winding layer length*
L_2—Secondary winding layer length*
N_2—Secondary turns
Z_B—Impedance of external burden $= R_B + jX_B$
R_B—Resistance of external burden in ohms
X_B—Reactance of external burden in ohms
R_2—Resistance of secondary winding
V_2—Secondary terminal voltage
E_2—Secondary induced voltage (that is, voltage induced by mutual flux and leakage flux)
E_{L_2}—Voltage induced in secondary by leakage fluxes
I_2—Secondary current in amperes
Φ_M—"Mutual flux" Φ_M will be considered to be entirely within the core (that is, it completes its circuit without entering or leaving the core)
Φ_{L_2}—Secondary leakage flux (that is, flux passing through secondary copper)
Φ_{L_0}—Leakage flux between windings (that is, flux passing between primary and secondary)
Φ_{L_1}—Primary leakage flux (that is, flux passing through primary copper)
Φ_C—The flux in the core at the center of the secondary coil (section 1 shown in figure 1)
$j = \sqrt{-1}$
$K = 2\pi f N_2\ (10^{-8})$ where f = frequency

* All dimensions in inches.

In order to compute the accuracy of a current transformer it is first necessary to define the term "accuracy". This can best be done by defining the inverse of accuracy, that is, the error. Fundamentally, the error of a current transformer is the vector difference between the primary and secondary ampere turns. Now this difference is, by virtue of the relative position of the primary and secondary coils, the number of ampere turns acting on the magnetic circuit of the transformer and is, therefore, the exciting current of the transformer in ampere turns. Hence, the rather intangible expression "accuracy" upon analysis becomes simply the inverse of exciting current.

It is, therefore, the first purpose of the following analysis to determine the exciting current. Only a wound-type transformer with two coils, one inside the other, will be considered in detail, but the general principles for the most part apply to any type.

In the development of the formulas the following assumptions will be made:

1. The secondary coil is inside the primary, which is usually the case.

2. The leakage flux flows parallel to the axis of the coil.

3. Flux density is zero on the outside of the primary copper and inside of the secondary copper, and increases linearly to the edges of the space between the copper of the two coils, the density on the primary side of the space being $3.2N_2I_2/L_1$ lines, secondary side $3.2N_1I_1/L_1$ making a mean density in the space of $3.2(2N_1I_1)/(L_1+L_2)$ all values being expressed in English units* (see figure 1 for symbols). Although it is obvious that the assumption regarding the conformation of the magnetic field is not exactly true, these assumptions are conventionally made in calculating reactance of transformers and have been shown to give values in good agreement with test.

4. In the computation of exciting current the ampere turns required for the core joints will not be considered separately. This procedure is usually permissible, if, as in the computations here presented, the core data used are derived from tests on a core having approximately the same number of joints per inch as the core of the transformer under consideration and if the joints are symmetrically disposed on the core. In some cases where the joints all happen to be in regions of flux density much higher than that in the rest of the core it may be necessary to consider the joints separately if the densities are high. This can be done by determining the density at the joints from the equations hereafter presented and adding the necessary ampere turns for the joints to the exciting ampere turns required for the rest of the core. Except on cores having short magnetic circuits or cores made of very high permeability material good lapped joints will not take a very large per cent of the total exciting current required for the core at low flux densities but usually will at high densities.

5. Much the same statement holds with respect to grain direction for cores in which the flux path is in different directions relative to the grain of the iron in different sections of the core, as the exciting current is usually higher when the flux flows across the grain than when it flows parallel to the grain.

6. The exciting currents will be treated as vectors in adding the exciting current for the various sections of the core, although it is not strictly correct to represent them as such since they are not in general sinusoidal. Experience, however, indicates that the errors introduced by assuming them so are negligible except possibly at quite high flux densities where the wave form of the exciting current is badly distorted.

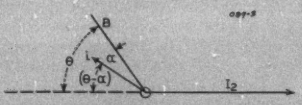

Figure 3. Vector diagram showing relation between flux density, exciting ampere turns, and secondary current for any particular core section

7. The magnitude of the leakage flux and its conformation are assumed to be dependent only upon the geometry of the apparatus, and the ampere turns in the coils, and are independent of the permeability of the magnetic core material. This assumption, of course, is valid only if the permeability of the core material is high relative to that of the air or other nonmagnetic media. Should the permeability of the core become quite low as the result of either a high overcurrent or a heavy burden which badly saturates the core, the configuration of the leakage flux may be altered, and its magnitude will no longer be strictly proportional to the ampere turns in the coils. This assumption limits the application of this method of analysis to conditions where the maximum magnetizing force in the core is about 300 ampere turns per inch or less.

8. It is also assumed in the analysis that with a sinusoidal primary current the secondary current will be a sine wave. For this assumption to be reasonable, it is necessary that the exciting current either be nearly sinusoidal or be a small per cent of the primary current. Actually the exciting current is almost never sinusoidal although it may be approximately so for the lower values of flux density; but it is usually, in good transformers, a small per cent of the load current. Therefore, the harmonics introduced by the exciting current are seldom of much consequence in the normal range of operation. However, here again, if due to either high overcurrent or a heavy burden, the core becomes saturated, the exciting-current wave form has large harmonics and the transformer error usually gets relatively large in which case the per cent of harmonics in the secondary current is likely to be appreciable.

If the harmonics thus introduced into the secondary current are large enough to be of concern, then a more precise and elaborate definition of accuracy is necessary as the ratio and phase-angle errors alone will no longer suffice to define completely the difference between the correct and the actual values of secondary current.

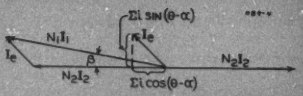

Figure 4. Vector diagram of relation between primary and secondary ampere turns and total exciting ampere turns for core of a current transformer

In figure 1 is shown a wound-type current transformer of a type which will be considered, and below it is a list of the principal symbols used. **Bold-face** type indicates a vector quantity, and all vectors will be referred to the secondary current as a base.

On the basis of the assumption relative to the distribution of leakage flux, the values of leakage flux are:

$$\Phi_{L_1}=3.2\frac{N_2I_2}{2L_1}A_1 \qquad (1)$$

$$\Phi_{L_0}=3.2\frac{N_1I_1}{L_1+L_2}2A_0 \qquad (2)$$

$$\Phi_{L_2}=3.2\frac{N_2I_2}{2L_2}A_2 \qquad (3)$$

In order to determine the exciting current it is first necessary to establish the

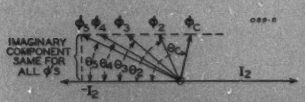

Figure 2. Phase angles between secondary current and fluxes in different sections of core

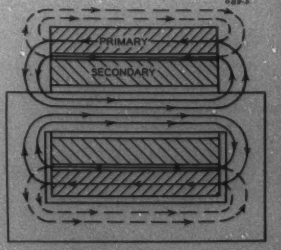

Figure 5. Paths of leakage flux which does not pass through secondary copper

* The factor 3.2 comes about as follows: For air using metric units flux density $B=H=0.4\pi NI/cm$ lines per square centimeter. Therefore, in English units $B=0.4\pi NI/in.\times 2.54$ lines per square inch.

flux density or densities in the core. This can most readily be done by beginning with Φ_C. To find Φ_C it will be assumed that the fraction of Φ_{L3} which returns inside the secondary is Y and that the fraction of $(\Phi_{L1}+\Phi_{L2})$ returning inside the secondary is U. The fractions Y and U are involved in the calculation of Φ_C in two ways. In the first place, it is apparent that

$$\Phi_C=\Phi_M+Y\Phi_{L3}+U(\Phi_{L1}+\Phi_{L2})$$

In the second place Φ_M is related to E_{L3} and E_3 by the relation

$$E_3=-jK\Phi_M+E_{L3}$$

whence

$$\Phi_M=\frac{j}{K}E_3-\frac{j}{K}E_{L3}$$

and it is obvious that E_{L3} will be dependent on the values of Y and U. In the appendix it is shown that

$$E_{L3}=-jKU(\Phi_{L1}+\Phi_{L2})-jK\Phi_{L3}\left(Y-\frac{1}{3}\right) \quad (4)$$

$$\therefore\Phi_M=\frac{j}{K}E_3-\frac{j}{K}\left[-jKU(\Phi_{L1}+\Phi_{L2})-iK\Phi_{L3}\left(Y-\frac{1}{3}\right)\right]$$

or

$$\Phi_M=\frac{j}{K}E_3-U(\Phi_{L1}+\Phi_{L2})-\Phi_{L3}\left(Y-\frac{1}{3}\right)$$

Substituting this value of Φ_M in the equation of Φ_C above gives

$$\Phi_C=\frac{j}{K}E_3-U(\Phi_{L1}+\Phi_{L2})-\Phi_{L3}\left(Y-\frac{1}{3}\right)+Y\Phi_{L3}+U(\Phi_{L1}+\Phi_{L2})$$

$$\therefore\Phi_C=\frac{j}{K}E_3+\frac{1}{3}\Phi_{L3} \quad (5)$$

It is, therefore, evident that it makes no difference in the value of Φ_C what assumptions are made regarding the return of the leakage flux since neither Y nor U occurs in the expression for Φ_C.

Referring to the last equation since Φ_{L3} has already been expressed in terms of I_3 (equation 1), it is now necessary to determine E_3 in terms of I_3. This is readily accomplished by adding the internal secondary IR drop to the secondary terminal voltage since E_3 by definition is the net voltage induced by all fluxes including leakage.

$$\therefore E_3=V_3+I_3R_3$$

but

$$V_3=I_3R_B+jI_3X_B$$
$$\therefore E_3=I_3(R_3+R_B)+jI_3X_B$$

Substituting in equation 5 this value of E_3 and the value of Φ_{L3} given in equation 1 in terms of I_3 gives

$$\Phi_C=I_3\left[\frac{j}{K}(R_B+R_3)\right]+\frac{j}{K}(jI_3X_B)+\frac{1}{3}\left(3.2\frac{N_3I_3}{2L_3}A_3\right)$$

or

$$\Phi_C=I_3\left[\frac{j}{K}(R_B+R_3)-\frac{X_B}{K}+.533\frac{N_3A_3}{L_3}\right] \quad (6)$$

To determine the fluxes at other points in the core it is necessary to know how much of the leakage enters the core between various points in its length. In general, it can be assumed that all the leakage flux which passes through and between the copper inside the core window enters the core. Of the remainder about 50 per cent will enter the core between sections 1 and 5.

If Φ_{LT} = flux entering the core between sections 1 and 5,

$$\Phi_{LT}=(\Phi_{L1}+\Phi_{L2}+\Phi_{L3})\times\left[\frac{h}{MLT_0}+\frac{1}{2}\left(1-\frac{h}{MLT_0}\right)\right]$$

Where h = height of core in the case of a "core" type core or twice the height in the case of a shell-type core and MLT_0 = mean length in the direction of the windings around the space between the windings

$$\therefore\Phi_{LT}=\left(\frac{\Phi_{L1}+\Phi_{L2}+\Phi_{L3}}{2}\right)\left(1+\frac{h}{MLT_0}\right)$$

Of Φ_{LT} a certain fraction, K_1 will enter the core between sections 1 and 2, another fraction, K_2, will enter between 1 and 3, and another fraction, K_3, between 1 and 4. The values of K_1, K_2, K_3, will be usually in the neighborhood of 0.57, 0.87, and 0.93 respectively. With these values of leakage flux entering the core the values of flux at the sections 2, 3, 4, and 5 will be given as follows, the subscripts after the Φ denoting the section:

$$\Phi_2=\Phi_C-K_1\Phi_{LT}=I_3\left[\frac{j}{K}(R_B+R_3)-\frac{X_B}{K}+\frac{0.533N_3A_3}{L_3}\right]-K_1\Phi_{LT} \quad (7)$$

$$\Phi_3=\Phi_C-K_2\Phi_{LT}=I_3\left[\frac{j}{K}(R_B+R_3)-\frac{X_B}{K}+\frac{0.533N_3A_3}{L_3}\right]-K_2\Phi_{LT} \quad (8)$$

$$\Phi_4=\Phi_C-K_3\Phi_{LT}=I_3\left[\frac{j}{K}(R_B+R_3)-\frac{X_B}{K}+\frac{0.533N_3A_3}{L_3}\right]-K_3\Phi_{LT} \quad (9)$$

$$\Phi_5=\Phi_C-\Phi_{LT}=I_3\left[\frac{j}{K}(R_B+R_3)-\frac{X_B}{K}+\frac{0.533N_3A_3}{L_3}\right]-\Phi_{LT} \quad (10)$$

The flux densities, β_C, β_2, β_3, β_4, and β_5 corresponding to the fluxes Φ_C, Φ_2, Φ_3, Φ_4, and Φ_5 are, of course, the absolute values of these fluxes divided by the cross-sectional areas of the core at the respective points, and the sines of the angles θ_C, θ_2, θ_3, θ_4, and θ_5 between β_C, β_2, β_3, β_4, and β_5 respectively and the secondary current reversed are the imaginary components of the fluxes divided by the absolute values (see figure 2). It should be noted that θ_C may be greater than 90 degrees.

If α_C, α_2, α_3, α_4, and α_5 (figure 3) are the angles between the flux densities and

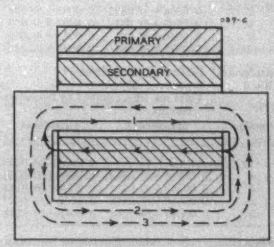

Figure 6. Paths of leakage flux which does pass through secondary copper

their respective unit values of exciting ampere turns* i_C, i_2, i_3, i_4, and i_5, as determined from magnetization data on the iron, then by averaging the values for each section of length the components of exciting ampere turns in phase with the secondary current reversed will be:

$$\frac{L_{12}}{2}[i_C\cos(\theta_C-\alpha_C)+i_2\cos(\theta_2-\alpha_2)] \quad \text{for section 1–2}$$

$$\frac{L_{23}}{2}[i_2\cos(\theta_2-\alpha_2)+i_3\cos(\theta_3-\alpha_3)] \quad \text{for section 2–3}$$

$$\frac{L_{34}}{2}[i_3\cos(\theta_3-\alpha_3)+i_4\cos(\theta_4-\alpha_4)] \quad \text{for section 3–4}$$

$$\frac{L_{45}}{2}[i_4\cos(\theta_4-\alpha_4)+i_5\cos(\theta_5-\alpha_5)] \quad \text{for section 4–5}$$

Where the L's represent the lengths between the sections denoted by the subscripts. Since there are two of each of the above sections in the whole core the total component of exciting ampere turns in phase with the secondary current reversed will be given by

$$\Sigma i\cos(\theta-\alpha)=L_{12}i_C\cos(\theta_C-\alpha_C)+(L_{12}+L_{23})i_2\cos(\theta_2-\alpha_2)+(L_{23}+L_{34})i_3\cos(\theta_3-\alpha_3)+(L_{34}+L_{45})i_4\cos(\theta_4-\alpha_4)+L_{45}i_5\cos(\theta_5-\alpha_5)$$

Similarly the component of exciting am-

* These quantities here represent actual ampere turns per inch.

Table I. Core Flux

Transformer No. 1	Secondary amperes = 4.89 Burden = 0.533 ohm R and 0.878 ohm X Volts per turn referred to secondary current	
Section	Measured	Calculated
1	0.0158+j0.0052	0.0152+j0.0067
2		0.0152+j0.038
3		0.0152+j0.055
4	0.0165+j0.0538	0.0152+j0.059
5	0.0164+j0.0583	0.0152+j0.063
Transformer No. 2	**Secondary short-circuited** Secondary amperes = 4.89 Volts per turn referred to secondary current	
Section	Measured	Calculated
1		0.0065−j0.0076
2	0.0064+j0.0315	0.0065+j0.035
3	0.0063+j0.057	0.0065+j0.058
4	0.0066+j0.061	0.0065+j0.062
5	0.0075+j0.064	0.0065+j0.067
Transformer No. 3	**Secondary short-circuited** Secondary amperes = 4.85 Volts per turn referred to secondary current	
Section	Measured*	Calculated
1		0.0058−j0.0033
2	0.00616+j0.0064	0.0058+j0.0064
3	0.00630+j0.0113	0.0058+j0.0115
4	0.00640+j0.0125	0.0058+j0.0127
5	0.00656+j0.0144	0.0058+j0.0138

*Values are average of values obtained on two transformers. Samples differed by almost 20 per cent.

Transformer number 1—General Electric type *KF-85.*

Transformer number 2—General Electric type *KF-58.*

Transformer number 3—General Electric type *WF-12.*

pere turns 90 degrees out of phase with the secondary current is given by

$$\Sigma i \sin(\theta-\alpha) = L_{11} i_C \sin(\theta_C-\alpha_C) + (L_{12}+L_{23}) i_2 \sin(\theta_2-\alpha_2) + (L_{23}+L_{34}) i_3 \sin(\theta_3-\alpha_3) + (L_{34}+L_{44}) i_4 \sin(\theta_4-\alpha_4) + L_{45} i_5 \sin(\theta_5-\alpha_5)$$

Since these components of exciting ampere turns must be added to the secondary ampere turns reversed to obtain the primary ampere turns the latter are given by

$$N_1 I_1 = -N_2 I_2 - \Sigma i \cos(\theta-\alpha) + j\Sigma i \sin(\theta-\alpha)$$

as shown in figure 4.

Therefore, ratio correction factor is†

$$RCF = \sqrt{\left[1+\frac{\Sigma i \cos(\theta-\alpha)}{N_2 I_2}\right]^2 + \left[\frac{\Sigma i \sin(\theta-\alpha)}{N_2 I_2}\right]^2}$$

and the phase angle is

$$\beta = \sin^{-1}\frac{\Sigma i \sin(\theta-\alpha)}{N_1 I_1}$$

If the common method of compensating by changing secondary turns is employed this percentage, of course, must be subtracted from the value computed above.

† This equation for ratio correction factor, of course, applies only to uncompensated transformers.

Other special methods of compensation require special calculations of their own to compute the final accuracy, although it is usually necessary to compute the uncompensated accuracy first in any event.

Discussion and Review

An inspection of the results of the analysis reveals some interesting facts. In the first place equations 6 to 10 inclusive show that the component of flux 90 degrees out of phase with the secondary current is the same in all sections of the core.

Actually this is not strictly true as in transformers having large primary conductors the eddy currents tend to make the leakage flux lag the primary current so that a component of the leakage shows up 90 degrees out of phase with the primary and secondary turns. The magnitude of this component of the leakage flux however, is almost always quite small compared to the average value of total flux in the core as shown by table I.

Equations 6 and 10 show that if the external burden and internal resistance are small Φ_C and Φ_L may be almost 180 degrees apart. This may seem unreasonable but actual flux measurements on the core show it to be true.

It will be noticed that no mention has been made of secondary reactance. The term was not used because it necessitates defining a rather elusive quantity which is not of any particular value in solving the problem. The term is elusive and confusing because reactance, being volts divided by amperes, depends on the voltage induced by the secondary leakage flux which, as has been seen, depends on the direction of return of this leakage. Moreover, the secondary leakage flux, Φ_{L2} must return outside the secondary coil if the in-phase component of Φ_C is negative, as is generally the case (see equation 6), because if one is to adhere strictly to physical realities there cannot be flux flowing in opposite directions in the same section of the core at the same instant. If Φ_{L2} does all return outside the secondary, the voltage generated is positive and hence the reactance must be negative. If, on the other hand, the in-phase component of Φ_C is $+1/3\ \Phi_{L2}$, the maximum value without leading power factor burden, then $1/3\ \Phi_{L2}$ returns inside the secondary. Referring to equation 4 this means $Y = 1/3$ and hence the voltage induced by the secondary leakage flux equals zero. Therefore, if reactance is to be defined in the conventional manner and the flux paths are to be taken exactly as they are, the only conclusion is that the secondary reactance is a variable depending on the external burden and varying between zero and $-K\Phi_{L2}/3I_2$. It is consequently evident that the use of the term "secondary reactance" is of no advantage in this analysis, as a rigorous definition of such a term makes it necessary to solve most of the problem to determine the reactance.

Tables I, II, and III give comparisons of calculated and measured results. Transformers numbers 1 and 2 were different in size but of similar design while the proportions of transformer number 3 were considerably different from the first two. An inspection of the tabulated values shows that there is still some room for improvement in the accuracy of the calculations which further study and added refinements might produce. On the other hand, the discrepancies between the calculated and the measured values of flux are no greater than the errors frequently incurred in computing the physical dimensions of the coils and the space between them. In fact, to go even further, tests show that in some cases the variation between individual samples of the same design is greater than the error of the calculations. Moreover, both tests and simple computation show that what appears to be a small degree of dissymmetry in the coils will frequently cause a large difference between the values of flux in the opposite ends of the core. From a practical point of view, therefore, further refinement in the method of calculating the flux will not produce the improvement in over-all results which would be expected at first glance.

Moreover, any such refinements in the calculations would be largely a matter of field theory in determining the exact conformation of the leakage flux outside the core rather than any alteration of the principle involved and in the writer's

Table II

Transformer Number 1—Leakage Fluxes, Secondary Short-Circuited, Secondary Amperes = 5.0

	Crest Values of Flux	
	Measured	Calculated
Φ_{L1}	9,450	8,750
$\Phi_{L2}+\Phi_{L1}$	35,650	28,000
$\Phi_{L3}+\Phi_{L2}+\Phi_{L1}$	35,100	36,800
Negative flux at center of secondary	3,490	2,920
Flux in item above divided by Φ_{L2}	0.37	0.33
Φ_{LT}	20,270	21,500
$\left[\frac{\Phi_{LT}}{\Phi_{L3}+\Phi_{L2}+\Phi_{L1}}\right]$	0.578	0.585

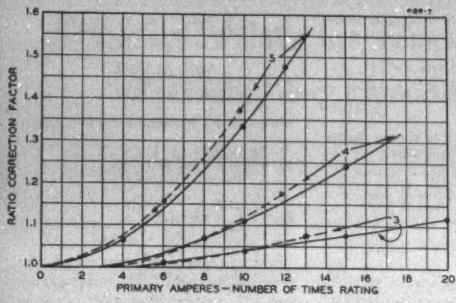

Figure 7. Overcurrent accuracy, transformer number 2 (see table I)

Burdens (volt-amperes based on five amperes):
3—50 volt-amperes, 50 per cent power factor
4—100 volt-amperes, 50 per cent power factor
5—200 volt-amperes, 50 per cent power factor
Solid curves—Test values
Dashed curves—Calculated values

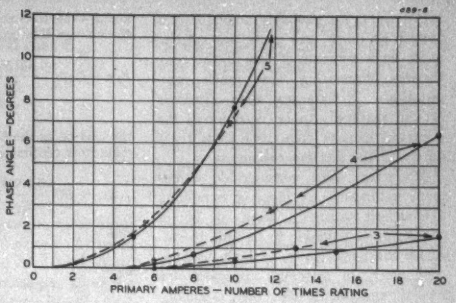

Figure 8. Overcurrent accuracy, transformer number 2 (see table I)

Burdens (volt-amperes based on five amperes):
3— 50 volt-amperes, 50 per cent power factor
4—100 volt-amperes, 50 per cent power factor
5—200 volt-amperes, 50 per cent power factor
Solid curves—Test values
Dashed curves—Calculated values

opinion the chief value in the foregoing analysis is the establishment of the general theorem by which the flux densities in the core can be determined from a given conformation of leakage flux, ampere turns, secondary burden, etc. A concrete illustration of this statement is afforded by the bar or through-type transformer having a single primary turn. In this type the magnetic field is altogether different from the wound type, and a totally different method of evaluating the leakage flux must be used, but having established the values of leakage flux entering the core the method of determining the flux densities in the core is exactly the same as with the wound type. In passing it might be mentioned that in the case of high-current bar or through-type transformers, particularly those with only two secondary coils, the leakage flux is generally of much more importance than in other designs.

A detailed discussion of a precise definition of accuracy including the effects of wave-form errors is beyond the scope of this paper, but since the exciting current is responsible for the added complications of harmonics the subject of wave form should not be passed over without mentioning the importance of the method of making exciting-current tests. At high flux densities in magnetic cores harmonics become a large per cent of the effective values of voltage or current or both depending on the test setup, and results may vary over a wide range depending on the wave form of voltage applied and the methods of measurement. On the basis of both experience and theoretical considerations, in the writer's opinion, the most satisfactory method of making exciting-current tests for current-transformer accuracy calculations is to apply a sine-wave voltage to a coil of low resistance wound on the core, and measure both the current and the voltage with an instrument such as a vibration galvanometer or separately excited dynamometer instrument which will give the fundamental components of the voltage and current waves. For tests at very high density the actual transformer coils and core should be used, the exciting current being applied to the primary coil and the voltage measured on the secondary.

While the method of calculation here presented is subject to the limitations implied in the assumptions and discussed previously, it can be used with reasonably good results for the calculation of overcurrent accuracy up to a current where the maximum magnetizing force in the core is about 300 ampere turns per inch. For many cases this will be high enough. Curves, figures 7 and 8, show results that may be expected up to limit specified. On some transformer designs which by virtue of their geometry have no leakage entering the core, the flux density in the magnetic circuit is uniform throughout its length. In such cases, the overcurrent calculations can be carried out successfully above the limit specified above.

With regard to the practical value of the method of calculation here presented, the method is quite useful in designing transformers to meet special requirements or specifications. It is also valuable in comparing the worth of proposed designs, and its value in this respect is enhanced by the fact that to test such proposed designs it is necessary to make several samples on account of the uncertainty with most core materials in obtaining a representative core in any particular sample. Another value in the method of calculating the accuracy is to be able to compare the relative advantages of different core materials in a given design, where again, if actual tests are made a number of cores will usually have to be tried before a representative sample is obtained. However, in this case where

Table III. Accuracy (Without Wilson Compensation)

Transformer Number	Burden (Ohms)	Secondary Amperes	Measured Values: Ratio Correction Factor	Measured Values: Phase Angle (Minutes)	Calculated Values: Ratio Correction Factor	Calculated Values: Phase Angle (Minutes)
1	$R=0.24$, $X=0$	0.5	0.9994	5	1.0002	4
		5	0.9961	0.5	0.9964	0
	$R=0.98$, $X=1.53$	0.5	1.0043	7	1.0050	6.5
		5	0.9979	−0.5	0.9983	−1
3	$R=0.24$, $X=0$	0.5	1.0054	17	1.0059	17
		5	1.0030	6	1.0029	6
	$R=0.98$, $X=1.53$	0.5	1.0158	17	1.0165	17
		5	1.0064	1	1.0070	1

transformers are probably available it is almost as quick and more accurate to make measurements of flux in the core, thereby eliminating that much computation. If data are then available on the materials to be considered, the accuracy can be computed from these data and the flux measurements.

Moreover, since considerable equipment and expense are involved in making overcurrent accuracy tests, it is, of course, quite valuable to be able to calculate the performance at high currents particularly in designing apparatus for special requirements when there is usually not time to build and test samples.

Appendix

Voltage Induced by Leakage Flux in Secondary; Proof of Equation 4

In verifying equation 4, first consider the leakage ($\Phi_{L0}+\Phi_{L1}$) figure 5. Since all this flux in traversing the space occupied by the coils passes outside the secondary copper, all that returns along the paths represented by the solid lines links all the secondary turns and all that returns along the dotted paths links no secondary turns. Hence, the voltage induced by the amount that returns outside the secondary will be zero and that which returns inside the secondary coil will generate a voltage equal to $2\pi fN_2 10^{-8}U(\Phi_{L0}+\Phi_{L1})$ since U is by hypothesis the fraction returning inside the secondary. Also, since $U(\Phi_{L0}+\Phi_{L1})$ is in phase with the secondary magnetomotive force the voltage generated is $-jKU(\Phi_{L0}+\Phi_{L1})$ referred to the secondary current.

To determine the voltage generated by Φ_{L2} consider any one particular line of flux as shown in figure 6. Let the fraction of the secondary turns between this line of flux and the inside of the secondary coil equal S. If the line of flux returns along the path number 1, the voltage generated is $-jKS$. If, on the other hand, the line of flux returns along path number 2, the voltage is $+jK(1-S)$. The algebraic difference, $jK(1-S)-(-jKS)$ is readily seen to be jK. Hence, the difference in generated voltage obtained by changing the return of the flux line from path number 1 to path number 2 is jK and is the same as the voltage generated by a line following path number 3. But the flux line considered is any line passing through the secondary copper, and, therefore, the result must be true for all such lines. Consequently, the voltage difference due to changing the paths of N such lines from inside to outside is jKN. Therefore, if the voltage generated by assuming all Φ_{L2} returns along path number 1 is E_0, the voltage E_A, generated when $(1-Y)\Phi_{L2}$ lines return along path number 2 is $E_A=E_0+jK(1-Y)\Phi_{L2}$ where Y is, of course, the fraction of Φ_{L2} returning inside the secondary as assumed in equation 4.

It can be shown* that if d_1 = the mean radius of the inside of the secondary coil (that is, $1/\pi$ times the length at the inside turn) and d_2 = the thickness of winding in inches, the voltage E_0 is given by the equation

$$E_0=-j2\pi f\left\{\frac{0.8\pi^2N_2^2I}{L_2}\left[\frac{d_1d_2}{3}+\frac{d_2^2}{4}\right]\right\}\times \quad (2.54)10^{-8}$$

the 2.54 being the factor to change the formula from centimeters to inches.

$$\therefore E_0=-jK\left(\frac{6.4N_2I_2}{L_2}\right)\left[\frac{d_1d_2}{3}+\frac{d_2^2}{4}\right](\pi)$$

and

$$\Phi_{L2}=\frac{6.4N_2I_2}{L_2}\left[\frac{d_1d_2}{2}+\frac{d_2^2}{3}\right](\pi) \qquad (11)$$

$$\therefore\frac{E_0}{\Phi_{L2}}=-jK\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right)$$

or

$$E_0=-jK\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right)\Phi_{L2}$$

$$E_A=-jK\Phi_{L2}\left[\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right)+Y-1\right]$$

since

$$E_A=E_0+jK(1-Y)\Phi_{L2}$$

or

$$E_A=-jK\Phi_{L2}\left[Y-\left\{1-\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right)\right\}\right]$$

if

$$\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right) \qquad (12)$$

is set equal to q and m equal to $(1-q)$, then

$$E_A=-jK\Phi_{L2}[Y-m] \qquad (13)$$

It is evident that q will be between $^2/_3$ and $^3/_4$. As a matter of fact, it will be generally very nearly $^2/_3$ making m very nearly $^1/_3$. It can, moreover, be shown that the value of $m\Phi_{L2}$ is exactly the same if Φ_{L2} is calculated as shown in equation 1 and m is taken equal to $^1/_3$ as it is if m and Φ_{L2} are computed as shown in formulas 11 and 12.

Using the latter combination it is seen that

$$m\Phi_{L2}=(1-q)\Phi_{L2}=\left[1-\left(\frac{\frac{d_1}{3}+\frac{d_2}{4}}{\frac{d_1}{2}+\frac{d_2}{3}}\right)\right]\times$$

$$\left[6.4\pi\frac{N_2I_2}{L_2}d_2\left(\frac{d_1}{2}+\frac{d_2}{3}\right)\right]$$

$$m\Phi_{L2}=6.4\pi\frac{N_2I_2}{L_2}d_2\left(\frac{d_1}{2}+\frac{d_2}{3}-\frac{d_1}{3}-\frac{d_2}{4}\right)$$

$$m\Phi_{L2}=6.4\pi\frac{N_2I_2}{L_2}d_2\left(\frac{d_1}{6}+\frac{d_2}{12}\right)$$

whereas if Φ_{L2} is computed as in equation 1

$$\Phi_{L2}=\frac{3.2N_2I_2}{2L_2}\left[2\pi\left(d_1+\frac{d_2}{2}\right)d_2\right]$$

$$\Phi_{L2}=\frac{3.2N_2I_2}{L_2}\pi d_2\left(d_1+\frac{d_2}{2}\right)$$

$$=\frac{6.4\pi N_2I_2}{L_2}d_2\left(\frac{d_1}{2}+\frac{d_2}{4}\right)$$

$$\therefore\frac{1}{3}\Phi_{L2}=6.4\pi\frac{N_2I_2}{L_2}d_2\left(\frac{d_1}{6}+\frac{d_2}{12}\right)$$

which is exactly the same as the value of $m\Phi_{L2}$ above.

While the method of calculating Φ_{L2} as given in equation 1 gives a slightly lower value than that of equation 11 the value of Φ_{L2} is higher so that the total leakage $(\Phi_{L2}+\Phi_{L0}+\Phi_{L1})$ is practically the same either way; and equations 1, 2, and 3 are somewhat simpler to use.

Therefore, using the latter formulas for the leakage fluxes and taking $m=^1/_3$ it is evident from quotation 13 that

$$E_A=-jK\Phi_{L2}(Y-^1/_3)$$

Now the voltage generated by the leakage fluxes, E_{L2} has two parts, one, that generated by Φ_{L0} and Φ_{L1} shown in the first part of the appendix to be $-jK(\Phi_{L0}+\Phi_{L1})U$ and second, the part generated by Φ_{L2} which is E_A

$$\therefore E_{L2}=-jKU(\Phi_{L0}+\Phi_{L1})-jK\Phi_{L2}(Y-^1/_3)$$

This relation is readily seen to be equation 4 given previously.

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Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 Supplement to Electrical Engineering—Transactions Section.

* See "Principles of Alternating-Current Machinery" by Ralph R. Lawrence, second edition, pages 188 and 189.

Reference Values for Temperature, Pressure, and Humidity

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IN most engineering measurements the readings obtained at a given time depend upon a number of conditions, such as temperature and barometric pressure, existing at the time of the test. In some cases the effects are very small, compared to the accuracy desired in the result, and can be neglected. In other cases prevailing conditions have a decided effect on the numerical values of the test results. For instance, in a determination of the boiling point of water, it is very necessary to consider the barometric pressure. In measuring the flashover voltage of an insulator, the temperature, pressure, and humidity each has a measurable effect on the observed value. Therefore, it has become necessary to select standard conditions to which certain measurements may be referred. This permits measurements made in different laboratories or at different times in the same laboratory to be compared directly. Certain values have been chosen, such as 760 millimeters barometric pressure, to which measurements for any physical or electrical quantity usually are referred, regardless of where in the world a particular measurement is made. This is a very convenient practice and greatly simplifies comparisons and use of engineering data.

It is therefore proposed to consider reference values for the temperature, the atmospheric pressure, and the humidity of the air. Because of their influence on measurements and on the rating of apparatus, the effects of these conditions have been analyzed. Reference values have been selected and correction factors for nonstandard conditions determined by interested standardizing groups. Certain values have been chosen as reference values because of average conditions prevailing at the time original tests were made or because of ease in maintaining a certain condition. A review of current practices indicates that 20 degrees centigrade is a favored reference value for physical and chemical quantities in both United States and international use. On the other hand 25 degrees centigrade is deeply rooted in American electrical practice. The agreement on a barometric pressure of 760 millimeters is universal. With respect to humidity, there is not much consistency in the reference values used or in the units in which they are specified. Humidity is important in fewer cases and its effects have been appreciated and evaluated more recently.

At times there is little advantage in the use of one reference value over another and, lacking organized co-ordination, slightly different values have been introduced in various standards. Although it may be impractical to remedy this undesirable condition in all cases, it is hoped that the information collected here will help to avoid further complication by minimizing the reference values adopted in future standards.

From an engineering point of view there are two types of reference values; in one case the value is of the nature of an average to which values obtained throughout a range of conditions may be referred or corrected. In the second case the problem is one of maximum values rather than average. This condition occurs notably in connection with the thermal limits and therefore the rating of electrical machinery. For rating purposes, the engineer is interested principally in ambient temperatures exceeding certain values and the time during which they prevail. The ambient-tem-

Table I. Reference Temperatures for Physical Quantities*

Quantity	United States Preferred Reference Temperature (Deg)	International Preferred Reference Temperature (Deg)
Resistivity (Cu)	20C	20C
Conductivity (Cu)	20C	20C
Temperature coefficient of resistance (Cu)	20C	20C
Specific gravity (Cu)	20C	20C
Resistivity (metals)	20C	20C
Conductivity (metals)	20C	20C
Temperature coefficient of resistance (metals)	20C	20C
Specific gravity (metals)	20C	20C
Cross section (metals)	20C	20C
Surface resistivity (dielectrics)	18–25C	18–25C
Volume resistivity (dielectrics)	20C	20C
Conductivity (dielectrics)	20C	20C
Coefficient of linear expansion	20C	20C
Coefficient of cubical expansion	20C	20C
Meter length	0C	0C
Gas volume	0C	0C
Gas density	0C	0C
Air density	0, 15, 15.5C	15, 15.5C
15-degree calorie	15C	15C
British thermal unit	60F, 39F	60F, 39F
Thermal conductivity of air	0C	0C
Coefficient of thermal expansion	20C (Ranges)	20C (Ranges)
Density (Hg)	0C	0C
Density (H_2O)	4C	4C
Density (calcite)	20C	20C
Specific gravity (oils)	15/4C	20/4C
Weights (mass)	0C	0C
Refractive index (liquids)	20C	25C–18C
Refractive index (air)	15C	15C
Cold junction of thermocouples	0C	0C
Standard cell (Weston)	20C	20C
Standard cell (Clark)	15C	15C
Barometers (reference temperature)	0C	0C
Translational energy of molecule	0C	0C
Angstrom unit (wave length)	15C	15C
Range and velocity of alpha rays	0C	0C
Mobility of ions in gases	0C	0C
Resistance of international ohm	0C	0C
Contact potentials	15–25C	
Gauges for metal fits (ASA)	20C	
Ball and roller bearings (ASA)	20C	

*Smithsonian Physical Tables, Smithsonian Meteorological Tables, Chemical Handbook, Marks Mechanical Engineers Handbook, Penders Handbook, International Critical Tables, Physical and Chemical Tables (German).

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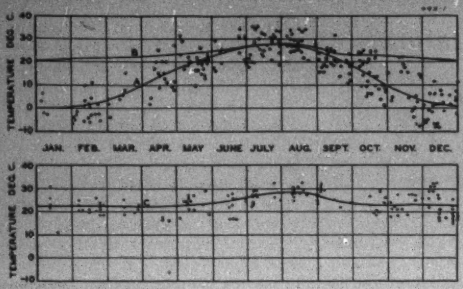

Figure 1

A—The temperatures at which high-voltage impulse tests were made outdoors at Sharon, 1936–38

B—The monthly average temperature curve indoors at Sharon, 1936–37

C—The temperatures at which high-voltage tests were made indoors at Trafford, 1936–39

perature considerations which determine apparatus rating are covered elsewhere,[5,12] notably in AIEE Standard No. 1.

In choosing and correcting to standard reference conditions, simplicity of the method is very desirable. Therefore, the reference value should be selected to represent approximately average actual conditions and to make the correction process as simple as possible. In this connection, the background and development of present standard reference conditions are discussed. Furthermore, the importance of dependable correction factors to convert performance data to the reference conditions is considered.

Temperature

(A). Reference Values

Certain specific values in connection with temperature are easily determined from well-known physical characteristics. The freezing and boiling points of water are examples. Another value is the point of maximum density of water at four degrees centigrade. In the beginning, the temperatures, at which measured quantities are given, depended upon the ease of obtaining certain temperature conditions. As progress was made the desirability of using a single or fewer reference temperatures became apparent. Table I shows some of the reference temperatures for physical and chemical quantities in United States and international use. These values were taken more or less at random from a number of standard handbooks and engineering tables. It is apparent from this table that 0 and 20 degrees centigrade are the reference temperatures now in most common use for such quantities.

Another common reference value which has been adopted, particularly for electrical-engineering use in this country, is 25 degrees centigrade. This value was established as the reference for testing apparatus. In the report of the standards committee and in companion papers presented at the 1913 AIEE midwinter symposium on standardization and apparatus rating,[1] the following parts sum up essentially the basis and reasons recognized at that time for selecting the 25-degree-centigrade value:

"The reference temperature in the guarantees should, therefore, be such as can easily be secured; that is, it should be the average temperature of the places at which the apparatus may be operated. This is from 20 degrees centigrade to 25 degrees centigrade and, as it is easier to raise than to lower the room temperature, the upper figure is advisable as a reference value. This reference temperature, therefore, should be chosen as 25 degrees centigrade, which is in accordance with the previous AIEE standard."

"It is, therefore, recommended . . . that all measurements and tests of electrical apparatus be based on a room temperature of 25 degrees centigrade."

At this same time, Chubb and Fortescue presented calibration data for the 25-, 37.5-, and 50-centimeter sphere gaps.[2] Although temperature and barometric pressure are not mentioned in their article, it is apparent from the discussions that the effect of these conditions was appreciated. The correction formula in use today for temperature and pressure was given by Peek in his discussion. The foregoing explains the use of 25 degrees centigrade in sphere-gap calibration tables in AIEE standards.[4] The use of this temperature has of course grown and for the past ten years, all high-voltage measurements have been referred to this temperature.

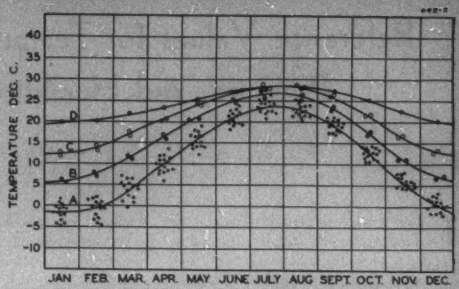

Figure 2. The average temperature curves for various regions in the United States (table IV)

A—Locations 1–15
B—Locations 16–17
C—Locations 18–19
D—Location 20

The present status of reference values in the electrical field is summed up in table III. In general, 25 degrees centigrade is the reference temperature specified for tests and test data on electrical apparatus in AIEE and ASA standards. On the other hand, AIEE standard on conductors refers to the 20-degree-centigrade temperature. International Electrotechnical Commission Standards[3] on high-voltage practice, insulators, and conductors are based on 20 degrees centigrade.

The American Society for Testing Materials has standardized a wide variety of electrical-insulating material tests for many of which temperature and humidity are important. Table II gives the reference values and specified testing ranges for a number of ASTM standards. This group has recognized the situation for some time and are aiming at a reference value of 25 degrees centigrade where possible.

(B). Temperature Conditions

For proper selection of reference values, the conditions of location of test as well as location of use are of interest. Therefore it should be useful, at this time, to consider the merits of different reference temperatures in the light of actual conditions recorded over a period of years at typical industrial establishments and of the values reported in the climatic summary of the United States Weather Bureau.[6]

(a). *Outdoor Use and Laboratories.* Figure 14 shows temperature readings over a period of several years at the Sharon, Pa., high-voltage laboratory of the Westinghouse Electric and Manufacturing Company, recorded in the course of commercial and

5. For all numbered references, see list at end of paper.

development testing of station apparatus. At this laboratory, tests on apparatus were made outdoors and the values shown, therefore, represent outdoor, daytime temperatures for Sharon. The range in temperature is from −9 degrees centigrade to 36 degrees centigrade, a total spread of 45 degrees centigrade. The annual average is about 15 degrees centigrade. The April–September average is about 24 degrees centigrade and during the winter months close to 0 degrees centigrade.

A detailed survey of these data plotted in figure 1*A* reveals that temperature variations during the day may affect the air density three to four per cent and even more from one day to the next. These variations are clearly apparent from figure 3, in which the daily maximum and minimum temperatures for Sharon covering the 24 hours during 1936 are given. Daily maximum variations frequently are 10 degrees centigrade, occasionally 15 degrees centigrade, and even more during marked changes in the atmospheric conditions. From similar charts, the annual average temperature during 1936–38 is 9.6 degrees centigrade, a value substantially lower than the 15 degrees centigrade annual average for figure 1*A*, since the former covers the full 24 hours of the day and thus includes the lower temperatures of the night. The chart for 1936 (figure 3) is of further particular interest as it shows a maximum peak temperature close to 41 degrees centigrade (July) and a minimum peak of −26 degrees centigrade (January), both of which, however, were sustained for a relatively short time. The spread between the more sustained maximum and minimum peak values is 60 degrees centigrade, to which there corresponds then a total air-density change of 22 per cent.

The climatic summary of the United States Weather Bureau gives data on temperatures that have been recorded at numerous stations located throughout the entire country. Average temperatures for 24 typical locations are listed in table IV. Locations 1 to 15 are distributed in the hot-summer and cold-winter region. This is the northeastern region between 38 degrees north and 45 degrees north latitude, which extends from approximately 105 degrees west longitude to the Atlantic Seaboard. In this region are located some three-quarters of the population and the major activities of the country. Curve *A* of figure 2 gives the temperature curve for this region as determined from these representative locations. Curve *B* is for two locations at approximately 34 degrees north latitude and curve *C* for two other locations on the 30 degrees north latitude. These curves clearly bring out the change in temperature cycle from north to south, that is, from the hot-summer and cold-winter region into the hot-summer and mild-winter region. Curve *D* is for the extreme southern fringe of the country. Due to the moderating meteorological influences on the Pacific Coast, the temperature for locations 21 to 24 (table IV) are more uniform than at corresponding latitudes in the east. For the northeastern region, the annual average (curve *A* of figure 2) is 11 degrees centigrade; the May-to-August average is 20.8 degrees centigrade. For the southeastern region, the annual average (curves *B* and *C*) is 18.7 degrees centigrade and the May-to-August average, 25.9 degrees centigrade. The annual average for the entire United States over a period of 50 years is 12.7 degrees centigrade.

In addition, the climatic summary gives the average maximum and minimum temperatures. These two limits vary from the average an amount depending on the location. For Pittsburgh which is an "average" location in the northeastern region, the spread of the average maximum and minimum temperatures from the annual average curve is about five degrees centigrade for practically the entire year. Much larger daily variations can occur as it is clearly shown in figure 3. The average temperatures for Sharon, Trafford, and East Pittsburgh come within one to two degrees centigrade of the Pittsburgh values (location 8 in table IV). It is apparent then that the temperature data recorded indoors and outdoors in testing apparatus, which are presented and discussed in this paper, are quite typical of conditions[13] that are expected elsewhere in the northeastern section of the country.

(*b*). *Typical of Large Factory Buildings, Machine Test Floors, and Large Laboratories.* Figure 1*C* shows temperature conditions for a period of years at the Trafford high-voltage laboratory. Here the testing is done indoors although the building is not well insulated and there are many places around doors which are not tight. It is seen that the average temperature throughout the year is around 23 degrees centigrade. This is very close to the standard temperature to which corrections are made. The variations in temperature measurements in this heated building are due to the high temperature gradient from floor to ceiling and represent conditions that generally are encountered in high-voltage laboratories. The distance from the floor to the roof is 65 feet and at times the gradient may reach 0.5 degree centigrade per foot. The temperature values shown in the figure were taken for all kinds of tests, but usually at the level at the apparatus being tested. For a rod gap on the floor, the temperature was measured 3 to 4 feet

Figure 3. The daily temperature variations at Sharon, 1936

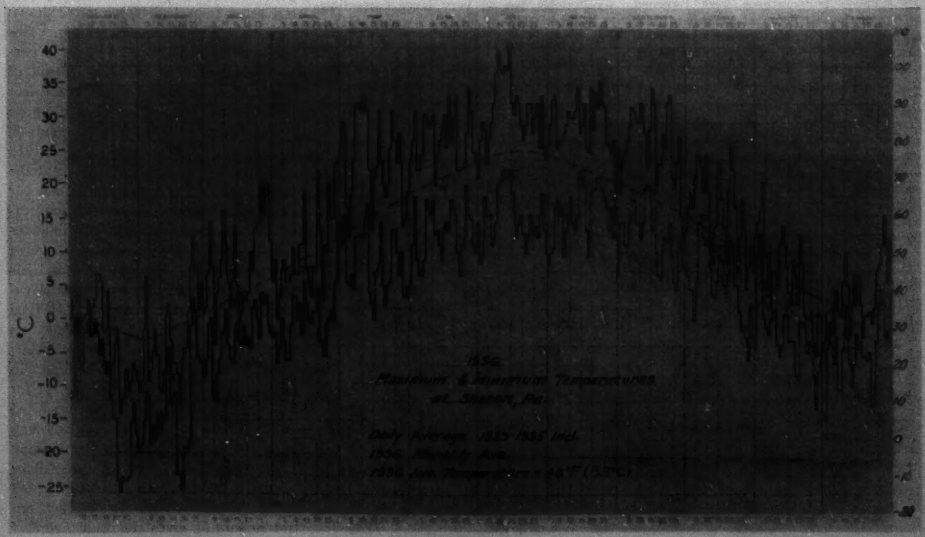

Table II. Reference Values and Testing Temperatures, in the Room-Temperature Range, Specified in October 1939 ASTM Standards on Electrical Insulating Materials

Material	Test or Treatment	Temperature or Temperature Range (Deg C)	Relative Humidity (Per Cent)
Sheet and plate	Physical	25 ± 8	
	Conditioning	25	40
Laminated tubes	Physical	25 ± 8	
Laminated rods	Physical	25 ± 8	
Varnished cloth	Elongation	20 to 30	
Varnishes	Density	25 ± 1	
	Viscosity	25 ± 0.2	
	Time of drying	25	
	Conditioning	25 water	
Varnished cloth	Conditioning	20 to 30	60 to 65
	Power factor	25 to 30	
Flexible varnished tubing	Conditioning	20 to 30	50 to 55
	Aging	20 approx.	
Shellac	Iodine number	21.5 to 22.5	
Shellac varnish	General	21 to 32	
	Iodine number and drying time	20 to 30	
	Special	20	65
	Specific gravity	20	
Molded materials	Tensile strength	20	
	Dielectric	25	
	Water absorption	25 ± 2	
Phenolic laminated sheet	Power factor	20 to 30	
Laminated tubes	Water absorption	25 ± 2	
Laminated round rods	Water absorption	25 ± 2	
Sheet and plate	Tensile strength	20	
	Rate of absorption	25 ± 2	
	Total absorption	20 to 30	
	Bonding strength	20 approx.	
	Hardness	25 ± 2	
Insulating oils	Dielectric	20 to 30	
Electrical porcelain	Tensile strength	20 approx.	
Filling and treating compounds	Power factor	20 to 25	
Untreated paper	Conditioning	20 to 30	65
Friction tape	Adhesion	20 to 22.2	less than 80
Rubber tape	Physical	20 to 28	
Rubber gloves	Electrical	15 to 32	
Asbestos yarns	Conditioning	21	65

above the floor and for a suspension-insulator string, the temperature measurement might be made as high as 30 feet above the floor. The average temperatures experienced indoors at Sharon are shown in figure 1*B*. These temperatures were recorded at one of the test floors where apparatus is subjected to the usual standard commercial tests as well as to other tests that may be required. The form of this average curve is practically similar to that of figure 1*C*.

(*c*). *Typical of Living Quarters Such as Homes, Offices, and Laboratories in Smaller Rooms.* In a well-heated building, consisting of smaller quarters, during the winter months, the temperature is 24 ± 1 degrees centigrade. This conclusion has been reached from the temperature measurements over a period of time in the engineering laboratory building at East Pittsburgh.

From the foregoing, therefore, the problem of reference temperature and correction factors is twofold. In the first place, the desirability of keeping corrections small should be kept in mind chiefly because of inaccuracies and variations in the original correction-factor data. The undesirable effect of discrepancies due to very large correction factors can be somewhat minimized by using reference values representing average conditions. Thus, for outdoor testing as in case (*a*), in correcting data to a standard temperature of 25 degrees centigrade the corrections are, in most cases, larger than if a lower temperature were used as a reference value. The 25-degree-centigrade reference value has merit for case (*c*) and also for case (*b*), though it is apparent that there is not much to choose between 25 degrees centigrade and 20 degrees centigrade in these two cases. However, as a general rule, it is desirable to have the reference temperature higher rather than lower than the average, for it is easier to heat than to refrigerate to obtain standard conditions for testing. The second part of the problem pertains to dependable correction factors which are desirable in view of the inherent variations in atmospheric conditions.

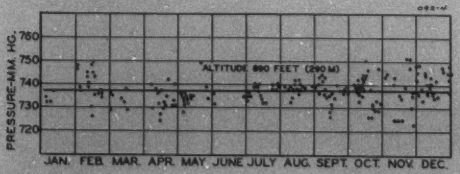

Figure 4. The barometric pressures for tests at Sharon, 1936–38

Barometric Pressure (Altitude)

The barometric pressure of 29.92 inches (760 millimeters) of mercury has been adopted universally as a standard reference value. This represents average conditions at sea level. The pressure of the atmosphere affects the thermal limits and the voltage rating of apparatus. Much apparatus is tested and used at elevations above sea level and consequently these effects cannot be ignored.

For a given location, however, the variations encountered in barometric pressure throughout the year are relatively small. Figure 4 shows readings at the Sharon laboratory during 1936–38. Each reading was taken at the time of a voltage flashover test. A ±1.5 per-cent band from the average includes practically all variations and a detailed examination of the records shows that diurnal variations seldom exceed 0.5 per cent. In a few instances only did the barometer vary from one day to the next as much as 2 per cent. To the meteorologist, these variations are an important measure of the trend in the weather or of prevailing conditions, but for the engineering purpose of this survey, the data hardly permit other than an average curve drawn through 735 millimeters mercury. This average value of mercury column corresponds quite well with the altitude of the Sharon laboratory which is 890 feet (290 meters). The effect of altitude on barometric pressure[7] is shown in figure 5.

The AIEE Transactions for 1913 indicate that the standards in use at the time prescribed a correction of one per cent of the observed rise in the temperature of apparatus for each 10-millimeter deviation from the standard pressure of 760 millimeters. The present standards state that specified ratings hold for elevations up to 1,000 meters. This is a gratifying example of the simplification of practice in using a reference value, which is so desirable. It is noted in passing that AIEE Standard No. 11 for Railway Motors states: "Machines rated in accordance with these standards may be tested at any altitude not exceeding 1,200 meters and no correction shall be applied to the observed temperature rise". AIEE Standard No. 16 for Railway Control Apparatus gives the usual figure of

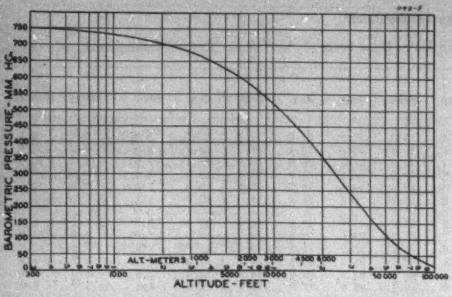

Figure 5. The effect of altitude on barometric pressure

1,000 meters. AIEE Standards for Transformers in addition to the 1,000-meter range give a correction for temperature rise tests made at altitudes greater than 1,000 meters.

At 1,000 meters the normal barometric pressure is 675 millimeters. Based on the old AIEE rule, an observed temperature rise at this altitude would be reduced eight per cent by the correction. As indicated above, present practice is to ignore altitude corrections up to 1,000 meters and to classify equipment for use at higher altitudes as "high-altitude apparatus". This applies to voltage as well as to thermal ratings. This simplification of the problem recognizes the impropriety of permitting a few applications to complicate the majority of ratings and measurements. For voltage flashover measurements, however, it is standard practice to combine barometric and temperature corrections under relative air density.

A recent occurrence is a backward step in progress toward uniformity of engineering practice. The United States Weather Bureau in July 1, 1939, adopted the practice of using the millibar as the unit of pressure. A bar is one dyne per square centimeter and 1,013.3 millibars corresponds to 760 millimeters, the standard atmospheric pressure. Several years ago the millibar was adopted for aerological observations and enjoys international use in this limited field. From an engineering point of view this action is regrettable. Barometric pressure invariably is expressed in terms of the height of a mercury column, both in standards and in laboratory practices. The use of Weather Bureau data will therefore require the use of a conversion factor.

The problem of barometric pressure in engineering measurements is a case where a single standard exists and where agreement on the unit of expression is reasonably consistent. Corrections have been minimized by standardizing on a range where possible. This fortunate situation is partly because the range of pressure variations in practice is small and the effects thereof on measurements and ratings correspondingly small. The growing use of electrical apparatus for aeroplanes eventually may lead to some modifications of present practices concerning ratings.

Humidity

Nearly 30 years ago the effects of humidity of the air on temperature rises of machinery were investigated and found to be negligible. It was also found that sphere-gap spark-over values were not influenced by humidity. Changes in

Table III. Reference Values in Apparatus Standards

Standard*	Apparatus	Reference Values** Temperature (Deg C)	Barometric Pressure (Mm)	Humidity (Mm Hg)	Correction Factors Specified
AIEE No. 4—1940	Measurement of test voltage in dielectric test	25	760	15.45	Relative air density
AIEE No. 41—1940	Insulator tests (insulators)	25	760	15.45	
AIEE—Bushings	Electrical Engineering, December 1934; AIEE Paper 40-37†	25	760	15.45	Relative air density, humidity, water resistance
ASA—1940—Proposed	Transformers, regulators, and reactors	25	760	15.45	Temperature rise above 1,000 meters
ASA—C50—1936	Rotating electrical machinery	25	760		Temperature cooling air and windage losses at high altitude
AIEE No. 19—1938	Oil circuit breakers	25	760	15.45	Voltage rating and temp. rise at high altitudes. Water resistivity
AIEE No. 23—1925	Disconnecting and horn-gap switches	Reference values and correction factors for numbers 22, 20, 28, and 26 substantially as in number 19			
AIEE No. 20—1930	Air circuit breakers				
AIEE No. 28—1936	Lightning arresters				
AIEE No. 26—1936	Automatic stations				
AIEE No. 18—1935	Capacitors	Leakage tests at 20 deg C			
AIEE Paper 40-38‡	"Recommendations for High-Voltage Testing"	25	760	15.45	Humidity corrections for rod gaps, insulators and bushings, relative air density
AIEE standards on conductors	Aluminum, copper, etc.	Resistance, temperature coefficient, and density of metal specified at 20 deg C			
IEC standards	High-voltage practice, insulators, and conductors	20	760	11	

* Some of the AIEE are also ASA standards.

** Apparatus standards almost invariably specify an altitude not exceeding 1,000 meters as usual service condition. AIEE Standard No. 11 ("Railway Motors and Other Electrical Machinery on Rail Cars and Locomotives") is the exception as it gives 1,200 meters.

† AIEE Transactions, volume 59, 1940 (October section), pages 590–1.

‡ Committee report, AIEE Transactions, volume 59, 1940 (October section), pages 598–602; also Electrical Engineering (AIEE Transactions), June 1937.

Table IV. Average Temperatures*

Climatic Summary of United States—Weather Bureau, United States Department of Agriculture (Degrees Centigrade)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
1. Boston, Mass.	− 2.1	− 2.0	2.4	8.0	14.1	19.2	22.2	21.0	17.6	12.0	5.8	0.1	9.8
2. New York, N. Y.	− 0.6	− 0.6	3.6	9.3	15.5	20.4	23.3	22.4	19.2	13.3	6.8	1.2	11.2
3. Philadelphia, Pa.	0.5	0.9	5.2	11.1	17.1	22.0	24.7	23.6	20.2	14.1	7.6	2.2	12.5
4. Baltimore, Md.	1.5	2.1	6.3	12.2	17.8	22.9	25.4	24.3	20.4	13.9	8.2	2.9	13.2
5. Washington, D. C.	1.0	1.8	6.3	12.0	17.8	22.5	25.8	23.7	20.2	13.9	7.5	2.5	12.8
6. Albany, N. Y.	− 4.7	− 4.6	0.8	8.0	14.8	19.9	22.6	21.4	17.5	10.9	4.3	− 2.1	9.2
7. Buffalo, N. Y.	− 3.8	− 4.3	− 0.2	5.9	12.2	18.0	21.0	20.3	16.8	10.4	3.9	− 1.6	8.3
8. Pittsburgh, Pa.	− 0.6	− 0.2	4.4	10.5	16.7	21.3	23.6	22.4	19.2	12.7	6.0	1.0	11.5
9. Columbus, Ohio	− 1.6	− 0.9	4.4	10.6	16.6	21.4	23.9	22.7	19.8	12.7	5.6	0.2	11.3
10. Detroit, Mich.	− 4.2	− 3.3	1.0	7.8	14.3	19.6	22.4	21.3	17.6	11.2	3.9	− 1.7	9.2
11. Indianapolis, Ind.	− 2.0	− 0.7	4.7	11.3	17.1	22.1	24.4	23.2	19.5	13.0	5.6	0	11.6
12. Chicago, Ill.	− 4.5	− 3.1	2.2	8.4	14.0	19.5	22.6	21.9	18.4	12.1	4.4	− 1.7	9.6
13. St. Louis, Mo.	− 0.2	1.6	7.0	13.6	18.9	23.8	26.3	25.2	21.2	14.3	7.0	1.5	13.4
14. Denver, Colo.	− 1.0	0.3	4.0	8.5	13.6	19.2	22.2	21.6	20.8	10.6	4.4	− 0.1	10.1
15. Salt Lake City, Utah	− 1.6	1.0	5.3	9.9	14.4	19.7	24.5	23.7	18.0	11.4	4.9	− 0.2	11.0
16. Atlanta, Ga.	6.1	7.5	11.5	16.1	20.7	24.5	25.7	25.2	22.8	17.0	11.0	7.0	16.3
17. Little Rock, Ark.	5.4	7.1	11.9	17.0	21.1	25.4	27.2	26.7	23.6	17.6	11.2	6.7	16.8
18. New Orleans, La.	12.6	14.0	17.3	20.6	24.1	27.2	28.0	28.0	26.4	21.7	16.7	13.1	20.8
19. Houston, Texas	11.8	13.3	17.1	20.8	23.9	27.3	28.5	28.4	26.1	21.5	16.3	12.5	20.8
20. Miami, Fla.	19.7	20.0	21.8	23.3	25.3	26.8	27.6	27.8	27.2	25.3	22.6	20.3	24.2
21. Seattle, Wash.	4.3	5.5	7.2	9.8	12.7	15.3	17.7	17.6	14.9	11.3	7.8	5.4	10.8
22. Portland, Ore.	3.9	5.7	8.4	11.1	14.1	16.8	19.5	19.4	16.5	12.5	7.9	5.1	11.8
23. San Francisco, Calif.	9.9	11.5	12.2	13.1	13.8	14.8	14.8	15.1	16.3	16.8	13.7	10.7	13.5
24. Los Angeles, Calif.	12.8	13.3	14.2	15.5	16.8	19.2	21.3	21.8	20.8	18.5	16.6	13.8	17.2

* Average for the various locations in from 40 to 100 years.

flashover values of insulators and point gaps with humidity were observed, but it was less than 10 years ago that more complete quantitative tests[8] were started. AIEE Standards No. 41 for insulators gave a formula for determining the humidity from the wet- and dry-bulb temperature readings in terms of the vapor pressure in inches of mercury and specified 0.6085 inch as the standard humidity. It was stated that flashover voltage shall be determined at or corrected to this standard humidity, but no correction factors were given and the control of humidity for much high-voltage testing was impractical. The standard humidity value was arrived at by choosing 65 per cent relative humidity at 25 degrees centigrade and 760 millimeters pressure as the standard. This represents average conditions in the summer months when many insulation troubles appear due to lowered leakage resistances and to the lightning season.

The annual humidity variations at the Sharon and Trafford laboratories as measured in the course of high-voltage testing are shown in figures 6 and 7 and may be regarded as typical of the more populated sections of the country. Diurnal variations in the absolute humidity of 0.10 inch mercury are common, but seldom exceed 0.20. From one day to the next, the humidity may vary from 0.20 to 0.30 inch mercury. The total spread for the year may reach 0.80 inch mercury, to which amount there corresponds a humidity correction factor of 25 per cent for some of the station and line apparatus. The annual average for the recorded data in the figures is close to 0.40 inch mercury. In the summer months, the average is above 0.60 inch mercury. It is at once seen that from a laboratory viewpoint the 0.6085 inch standard is too high. About 80 per cent of the testing is carried on at substandard conditions. This means a higher percentage correction factor and test results are correspondingly more at the mercy of the accuracy of the correction factors. These, of course, were based on a limited amount of data. However, the difficulties of changing the standard on which so much work has been based in determining insulation values and in setting insulation levels have made acceptance of the above undesirable feature much more attractive than the confusion of changing.

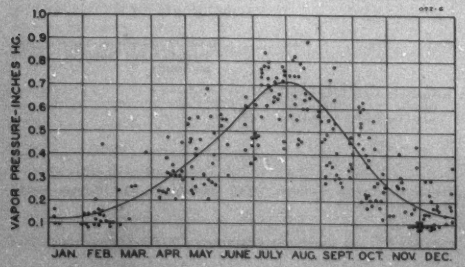

Figure 6. Humidity conditions at the Sharon high-voltage laboratory for outdoor tests, 1936–38

The laboratory subcommittee[9,10] of the EEI–NEMA Joint Committee on Coordination of Insulation have been working on the problem of the influence of humidity in connection with insulation problems for many years. Similarly, the International Electrotechnical Commission has carried on work of this nature abroad. The IEC has adopted a standard humidity of 11 grams per cubic meter, which corresponds to 0.45 inch vapor pressure. This is much closer to average testing conditions throughout the year. It would be convenient to have the United States and International standard agree to facilitate comparing data. This is a matter for the interested committees to consider. Fundamentally, the problem is one of the inconvenience of changing established values rather than of the intrinsic merits of a particular standard.

An undesirable situation prevails in connection with wet flashover testing. AIEE standards for circuit breakers and for transformers call for wet testing of bushings with a precipitation of 0.1 inch

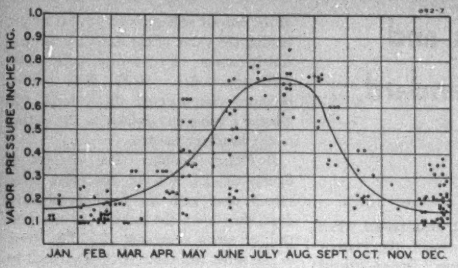

Figure 7. Humidity at the Trafford laboratory for indoor tests, 1934–38

per minute and a resistivity of 12,000 ohms per centimeter cube. AIEE standards for insulators specify wet flashover testing at a precipitation of 0.2 inch per minute and a water resistivity of 7,000 ohms per inch cube. AIEE standards for lightning arresters specify at least 0.1 inch of water per minute with the resistivity of 5,000 ohms per inch cube. The IEC groups have discussed standardizing on 3 millimeters per minute precipitation and 9,000–10,000 ohms per centimeter cube resistivity. A committee has been appointed to study and report on this situation and it is hoped that a simplification of testing procedures will result.

Summary

Reference values in present use are partly a product of history and were partly selected as a result of analysis. In some cases they represent average conditions and sometimes they do not. For certain applications different standardizing groups use different values and co-operative activities are thereby hindered.

An attempt has been made here to show the relation of reference values to variations found in practice. In most cases correction factors are available to correct measured values to standard conditions. The importance of correction factors is shown by figure 8 which gives the correction factor for humidity for the 60-cycle flashover voltage of suspension insulators. This indicates a correction of 16.5 per cent for tests made at 0.1 inch vapor pressure, a common condition in the winter months. Hence, from this point of view the selection of reference levels to minimize correction factors is to be recommended.

Attention is called to existing conditions, particularly where they are not conducive to easy comparisons of testing data and to simple testing procedures. It is hoped to stimulate the study of the problems involved and to assist present and future standardizing bodies in avoiding the confusion of the past and in organizing further work on a rational basis. At best all reference values and specified testing ranges must be a compromise for broader variations encountered by equipment under service conditions. Therefore, it seems reasonable to minimize the number and the ranges of the reference conditions.

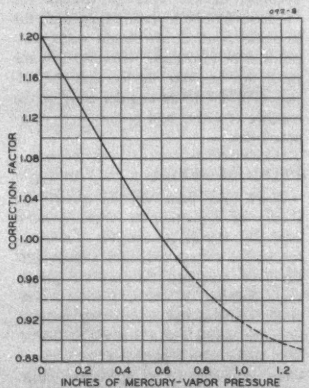

Figure 8. The importance of correction factors is indicated by the 20-per-cent spread in flashover voltages for the changes in absolute humidity indicated in figures 6 and 7

Humidity correction factors for 60-cycle flashover of rod gaps and suspension insulators: multiply measured kilovolts at humidity of abscissa by the correction factor

Standard humidity 0.6085 inch (15.45 millimeters)

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Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 Supplement to Electrical Engineering—Transactions Section.

Rating of Potential Devices and Suggested Material for a Standard

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THERE has been an evident need for an exposition of the factors relating to the rating of capacitance potential devices and to their application. It is our intention to review this situation indicating the several limitations which govern ratings and application, and to offer material which may be used in the preparation of standards for potential devices. Vacuum-tube equipment is not covered. The authors were requested by the AIEE relay subcommittee to write a paper outlining the basis of rating for the purpose of formulating standards.

Description of Device Circuits

The potential device may be defined as a voltage-transforming equipment used in conjunction with a high-voltage bushing or capacitor as a source of energy to provide a low voltage suitable for operating instruments and relays. The output voltage may be corrected by one of several means to obtain the desired instrument voltage and phase angle.

Lines of Devices

Practice has resulted in two varieties of capacitance devices, one for operation with bushings having a capacitance tap, and one for operation with coupling capacitors such as used for carrier-current work. The former is commonly referred to as a "bushing-potential device" and the latter as a "coupling-capacitor potential device".

Types of Devices

Practice has also resulted in two general types of devices as used with coupling capacitors, and they may be designated as "quadrature" and "in-phase", respectively. With the "quadrature device" the maximum output is obtained when the phase angle between the output voltage and the impressed line-to-ground voltage of the phase to which the device is connected through the coupling capacitor is approximately 90 degrees. With the "in-phase device" the rated output is obtained with these voltages substantially in phase. It is not essential, however, that the quadrature device always be adjusted for 90 degrees, and hence it may be more aptly termed "out-of-phase" device. It is essential that the in-phase device always be adjusted for the in-phase relation, to obtain rated output and performance. However in some cases, an in-phase device may be adjusted to obtain an angular shift at the expense of rating and performance characteristics.

Device Circuits

Much has been written about the theory of operation of these devices. Basically, the device consists of a transformer for voltage reduction and a reactance, or auxiliary burden, for phase-angle control. When used with a coupling capacitor the device may be connected in series with the main capacitor, or in shunt with a portion of it, whereas when connected to an apparatus bushing, the shunt arrangement only is used.

The most usual circuit arrangements are as shown in figure 1, (*a*)—(*f*).

Quadrature or Out-of-Phase Circuits. The circuit of figure 1*a* is the simplest and least useful and may be used when the phase angle of the secondary voltage is a matter of indifference and the load burden is exactly right to obtain the required voltage. If the load burden becomes disconnected the voltage rise will be limited only by the insulation strength of the transformer, or by the flashover of a protective gap. Its use should be discouraged.

Figures 1*b* and 1*c* are the circuits commonly used with the out-of-phase devices, and it should be noted that in figure 1*c* the auxiliary burden must include an inductive reactance to compensate for the capacitive reactance of C_2, if true quadrature performance is desired. The magnitude and phase angle of the output voltage is controlled by adjusting the value of the auxiliary burden, which consists of resistance, inductance, and capacitance. If the load burden becomes disconnected the voltage will assume a value determined by the setting of the auxiliary burden.

In-Phase Circuits. The circuits of figures 1*d*, 1*e*, and 1*f*, are those commonly used with the in-phase devices, depending upon the location of the control, or series, reactance Z_s. The value of the series reactance is closely equal to the reactance of the auxiliary, or shunt, capacitor C_3 and is adjustable, mainly for phase-angle control. The capacitor C_a is also adjustable in value to correct the power factor of the burden to unity. If the device secondary becomes short-circuited the voltage on the device primary will rise and be limited only by the losses or by the flashover of the protective gap.

Procurement of voltage at zero phase angle error primarily involves the use of a tapped bushing, tapped capacitor, or the equivalent, which in reality becomes a capacitance potentiometer. The tap voltage when supplying a totally capacitive burden will be in phase with the line-to-ground voltage of the coupling capacitor or bushing. A burden, other than zero power factor, will cause a phase displacement of the output voltage depending on its location in the circuit and the angular relation of the capacitor charging current and the burden current. This inherent phase displacement is corrected by the use of the inductive reactance Z_s.

Factors Affecting Rating

The rating of a potential device will depend upon economic and performance limitations that may be imposed. Factors involved in determining rating are:

1. Line voltage and frequency
2. Capacitance (electrostatic capacity) of the bushing or coupling capacitor
3. Permissible operating tap voltage on primary of device transformer
4. Insulation level of the device, and shunt or auxiliary capacitor
5. Characteristics and requirements of burden to be energized
6. Over-all performance requirements

Available Volt-Amperes

The maximum volt-amperes available for potential-device operation depends on the line-to-ground charging current through the bushing or coupling capacitor and the operating tap voltage at which the potential device diverts this current for instrument use. Roughly the prod-

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1. For all numbered references, see list at end of paper.

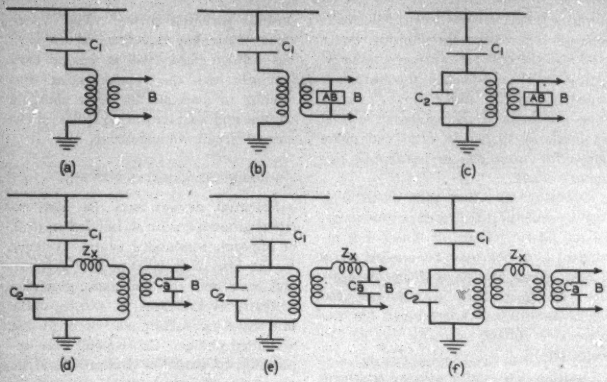

Figure 1. Typical circuits used for potential devices

C_1—Line-to-tap capacitance, sometimes coupling capacitance

C_s—Tap-to-ground capacitance, sometimes auxiliary capacitance, sometimes shunt capacitance

B—Useful burden

AB—Auxiliary burden for control

C_2—Power-factor-correction capacitance

Z_x—Series reactance for control

uct of these two quantities represents the maximum volt-amperes available from the transmission line. Practical considerations place a limit on the charging current and operating tap voltage. The voltage rating of the bushing, or the actual carrier coupling, fixes the capacitance. The operating line voltage and frequency determine the charging current that passes through this capacitance.

Watts Output

The output in watts of a potential device may be more accurately expressed:[1]

$$W = 2\pi f C_1 E E_2 \sin \alpha - K$$

where f is the system frequency, C_1 is the capacitance line to tap, E and E_2 are respectively the line and tap voltage to ground with the angle α between them. K represents the loss in the device network. The actual rating of a device is somewhat less than the maximum theoretically available to insure satisfactory operating performance. The term $2\pi f C_1 E$ is the charging current and term E_2 is the operating voltage at which the potential network is normally energized. This voltage usually dictates the insulation level of the transformer and the shunt or auxiliary capacitor which will be used in the circuit.

Effect of Series Reactance

The use of series reactance for phase-angle control (in-phase device) will affect the transformer operating voltage and the resultant voltage on the auxiliary, or shunt, capacitor. The circuit may be analyzed by several methods. However, without going into detail, the network resolves itself into an essentially parallel resonant circuit wherein the bushing or coupling capacitor capacitive reactances are fixed and the equivalent inductive reactance may be varied. The operating tap voltage will increase as the inductance in the circuit is increased, up to the point of resonance, for any fixed load impedance. The rating of a device must not be such that will result in a voltage across the tap and transformer in excess of their individual insulation ratings.

Protective Gap

A protective gap is connected across the tap circuit or transformer primary to provide overvoltage protection in service, and when so protected the device should be able to withstand the overvoltages to which the coupling capacitor or bushing may be subjected. The setting of this gap must be co-ordinated with the normal-frequency voltage that may be obtained during the fault period and with the voltage rating of the component parts of the circuit to be protected. The gap should not operate at less than twice normal voltage at normal frequency, otherwise incorrect voltage may be imposed on the relays. Thus the setting of an insulation level for the component parts of the device will depend on the maximum normal operating voltage of the tap circuit or potential transformer, which in turn will govern the output of the over-all equipment for a given voltage class of bushing or coupling capacitor. Naturally economic factors will also affect the setting of the insulation level and ultimate size of the equipment.

Burden Requirements

The requirements of the burden to be energized, such as phase angle displacement of the voltage and permissible ratio error will affect the required characteristics and rating of the device. For instance, if voltage indication only is required at normal operating voltages, device regulation and phase-angle displacement are of no concern and the simplest form of device would be satisfactory. On the other hand, if certain types of high-speed relays are to be energized a much more accurate device will be required. This latter type of burden requires an accurate reproduction of the primary voltage both as to phase angle and ratio over a large range of line voltage and secondary burden. Nonlinear burdens represent a special case and their use leads to instability of the combined device and burden circuit for certain conditions of operation.

Performance Features

The over-all performance of a device includes:

(*a*). *Performance Characteristics*

1. Regulation, or change in ratio and phase angle, with variation in burden, at constant applied voltage.

2. Regulation with variation in applied voltage, at constant burden impedance.

Note: The regulation is usually given on the basis that the device is initially adjusted for normal voltage and burden impedance.

(*b*). *Transient Characteristics*

The transient characteristics consist of the rapidity and fidelity with which the device follows changes in the system voltage, and the freedom from instability under normal and fault conditions.

Regulation

The ratio and phase-angle performance of a device may be represented by:[2]

$$E_b = E_{bo} - I_b Z \qquad E_{bo} = \frac{A}{n} E_h$$

where E_b and I_b are the burden voltage and current respectively; E_{bo} the no-load voltage; Z the total equivalent potential device impedance; E_h the line-to-ground voltage, A the relation between certain impedances, and n the ratio of the potential-device transformer. These relations show that increased burdens on a given device generally result in in-

creased ratio and phase-angle errors. This is due to the increased range of voltage on the potential device or tap circuit and to increased losses in the potential network.

Transients

Transient performance depends on the constants of the potential network used, the power factor, and type of the burden energized. All of these are interrelated with the device rating and the excitation requirements of the potential network.

Effect of Temperature Changes

The effect of temperature changes on the performance of potential devices may be considered in two steps: the effect inherent in the device itself; and the effect resulting from the changes in burden characteristics due to temperature changes. In the case of the in-phase device the temperature effect is practically negligible from either consideration for the usual conditions of operation.

Table I. Maximum Ratio and Phase-Angle Deviation With Variation in Applied Voltage

Per Cent Primary Voltage	Class A		Class B		Class C	
	Ratio (Per Cent)	Angle (Deg)	Ratio (Per Cent)	Angle (Deg)	Ratio (Per Cent)	Angle (Deg)
110	±1	±1	± 2	± 2	±2	± 5
100*	±1	±1	± 2	± 2	±2	± 5
85					±5	±10
25	±3	±3	± 6	± 6		
5	±5	±5	±12	±12		

* Device to be initially adjusted within these limits.

For the case of the out-of-phase device the inherent effect is also negligible except in regard to the coupling capacitance (auxiliary or shunt capacitance not used) for which a change of $2^1/_2$ per cent may take place for a temperature change from −20 degrees to 130 degrees Fahrenheit. Changes in burden, including the auxiliary burden, due to changes in temperature affect the performance in accordance with the characteristic curve.

Basis of Rating

Potential-device rating is expressed on definite primary and secondary voltages, the watts output, and the performance characteristics. The primary voltage ratings are the standard high voltages such as 115 kv, 138 kv, etc. The corresponding secondary voltages are 115 and/or 66.4.

The output rating of potential devices is given in watts, instead of volt-amperes as is customary for potential transformers. This is done because the watts output is actually the limiting factor and also the best performance characteristics are obtained when the burden is substantially at unity power factor. The performance characteristics consist in limits of change in ratio and phase angle for variations in burden or primary voltage.

Operation at other than rated high voltage will affect the rated output watts, or secondary voltage, or both. For instance, a device may be applied on a 138-kv circuit at a point where the operating voltage is 132 kv. In this case rated watts output may be obtained but the secondary voltage normally will be 110 volts, etc.

Another case is where the apparatus is operated at a circuit voltage corresponding to the next voltage class below normal insulation rating. For such a condition a special device must be used and the device output is derated in proportion to the reduction in primary voltage, and normal secondary voltages and performance characteristics obtained.

Effect of Bushing Capacitance

The low capacitance of apparatus bushings limits the charging current available for potential-device operation. Impulse characteristics of these bushings, and the apparatus in which they are installed, place a definite limit on the operating tap voltage and thus the capacitance of the tap for potential device operation. The higher-voltage bushings will have a larger charging current than the lower-voltage bushings and thus the bushing potential device ratings will vary with the voltage class of the apparatus bushing. These output ratings will vary for each of the accepted standards of primary voltage.

Effect of Coupling Capacitance

Coupling-capacitor potential devices will have the same rating for any voltage class and in general it is higher than for bushing potential devices. The capacitance of coupling capacitors for the various voltage classes will in general vary inversely with the voltage rating thus tending to maintain the same charging current and watt output regardless of the normal circuit voltage rating.

Grounded or Isolated Neutral

Potential devices may be used on either grounded-neutral, isolated-neutral, or impedance-grounded neutral systems. In the case of isolated-neutral systems, and sometimes for impedance-grounded systems, overvoltages in excess of the protective gap setting may occur on the unfaulted phases. Consequently the application of potential devices should be given special consideration under these conditions.

Choice of a Potential Device for Relaying

The in-phase device should be used where the following forms of relaying are involved: ground directional, phase directional, carrier pilot, pilot wire, distance.

The out-of-phase device may be used for any one of the following forms of relaying: ground directional, balanced current with voltage restraint, undervoltage or overvoltage. It should be noted that most directional ground relays are arranged for operation from in-phase devices. If an out-of-phase device is used, a change in the voltage circuit of the relay is generally necessary.

Ratio and Phase-Angle Characteristics

The potential device should be chosen having ratio and phase-angle accuracy commensurate with the degree of accuracy required of the relaying. Generally, the accuracy of any in-phase device is suitable for all except possibly some forms of distance relaying.

In the case of distance relaying using reactance-type elements, errors in current and voltage sources introduce the following error in distance measurement:

$$\text{Per cent error} = 100\left[1 - \frac{K_c \sin(\phi + \theta_p - \theta_c)}{K_p \sin\phi}\right]$$

where

K_c = ratio correction factor of current transformer
K_p = ratio correction factor of potential device
ϕ = power factor angle of line
θ_p = phase-angle error of potential device (positive if leading)

Table II. Maximum Ratio and Phase-Angle Deviation With Variation in Burden

Per Cent Burden	Class A		Class B		Class C	
	Ratio (Per Cent)	Angle (Deg)	Ratio (Per Cent)	Angle (Deg)	Ratio (Per Cent)	Angle (Deg)
100*	± 1	±1	± 2	± 2	±2	±5
50	± 6	±4	±10	± 5	**	**
0	±12	±8	±20	±10	**	**

* Device to be initially adjusted within these limits.

** Limits cannot be set on account of the varying relationship between values of useful and auxiliary burdens.

θ_e = phase-angle error of current transformer (positive if leading)

If the per cent error is a positive quantity, the distance measured will be less than the actual distance.

If impedance elements, which are not sensitive to phase angle, are used the error, usually small, can be expressed as:

$$\text{Per cent error} = 100\left(1-\frac{K_s}{K_p}\right)$$

Appendix

Suggested Material for a Standard for Potential Devices*

There is a need for co-ordinated practice in regard to potential devices and in this appendix there is presented material suitable for standards. It is hoped this will serve as the basis for the formulation of potential-device standards by the Institute.

These suggestions have been prepared by the authors, reviewed by the AIEE relay subcommittee, and are presented here for the purpose of bringing them to the attention of the industry for comment.*

Scope

These standards apply to potential devices for use with coupling capacitors and/or bushings.

Terminology

POTENTIAL DEVICES

The potential device may be defined as a voltage-transforming equipment used in conjunction with a high-voltage bushing or capacitor as an energy source, to provide a low voltage suitable for operating instruments and relays.

Note: The term "coupling-capacitor potential device" may be used to indicate use with coupling capacitors, and "bushing potential device" indicates use with bushings.

RATIO

The ratio of a potential device is the overall ratio of the line-to-ground voltage of the phase to which the device is connected to the secondary voltage of the device. (It is not the turn ratio of transformers used in the network.)

REGULATION

The term "regulation" designates the change in ratio and phase angle when the burden is varied over a specified range (burden regulation) with constant primary voltage; or when the line-to-ground voltage is varied over a specified range (voltage regulation) with constant burden impedance.

Standard Ratio

The standard ratio shall be such as to give standard rated secondary voltages at rated burden when coupling capacitors are used at their rated voltage.

Classification

Potential devices are divided into two types and three accuracy classifications.

In-phase type—zero phase-angle adjustment—two accuracy classes

Out-of-phase type—30 to 150 degrees phase-angle adjustment—one accuracy class

TYPES

In-Phase. The secondary voltage shall be adjustable to be closely in phase and have correct ratio with respect to the line-to-ground voltage of the phase to which the device is connected, and to remain so for all values of applied primary voltage and secondary burden within the rating of the device, subject to the allowable deviations as herein stated.

Out-of-Phase. The secondary voltage shall be adjustable to the desired phase angle and of correct ratio with respect to the line-to-ground voltage of the phase to which the device is connected, subject to the allowable deviation as herein stated.

CLASSES

The accuracy classifications are as follows:

Class *A*—High accuracy, in-phase type

Class *B*—Lower accuracy, in-phase type

Class *C*—Out-of-phase type—for use with coupling capacitors only

Rating

The rating of potential devices shall include

1. Circuit voltage
2. Line-to-neutral voltage
3. Maximum watts output
4. Secondary volts
5. Frequency

Performance Characteristics

The standard characteristics of potential devices shall be based on

(*a*). Rated line-to-ground voltage of the circuit

(*b*). A frequency of 60 cycles

(*c*). Standard secondary voltages

(*d*). Specified burden

For the in-phase devices the performance characteristics shall be based on a unity-power-factor burden.

Rated Watts Output and Standard Secondary Voltages

For coupling-capacitor potential devices the rated watts output and standard secondary voltages shall be:

Class	Main Winding		Auxiliary Winding	
	Watts	Secondary Volts	Watts	Secondary Volts
A	150	115/66.4	75	115
B	100	115/66.4	50	115
C	75	115		

For bushing potential devices the standard secondary voltages shall be as given in the following table. The rated watts output is dependent upon the standard bushing and is being studied further. It is hoped to reach a conclusion in time to incorporate the results in the adopted standards.

Rated Circuit Voltage (Maximum Kv)	Line-to-Neutral Voltage (Maximum Kv)	Secondary Voltage (Volts)
115	66.4	66.4 or 115
138	79.7	66.4 or 115
161	93.0	66.4 or 115
230	132.0	66.4 or 115
287.5	166.0	66.4 or 115

Performance Specifications

VARIATION IN APPLIED VOLTAGE

The regulation with constant burden impedance for variation in applied voltage shall not be greater than given in table I.

VARIATION IN BURDEN

The regulation with constant primary voltage for variation in burden shall not be greater than given in table II.

Output at 50 and 25 Cycles

The output shall be reduced to 80 per cent for use on 50-cycle circuits. For use on 25-cycle circuits a special design is required.

Deviation of Circuit Voltage

Standard performance characteristics at proportionately reduced output ratings shall be maintained for a reduction in voltage from 5 per cent up to 20 per cent (that is, use of coupling capacitor of the next higher voltage class, in which case the watts output rating shall be reduced 20 per cent and a special design is required).

Power-Factor Correction

Coupling-capacitor potential devices shall be provided with a tapped capacitor in the

* Publication of this material with this paper authorized by the AIEE committee on protective devices at the Niagara Falls meeting, May 17, 1940.

secondary circuit as follows: class *A*, 115 volt-amperes in 3.75-volt-ampere steps; class *B*, 75 volt-amperes in 5-volt-ampere steps.

In class *C* devices this feature is incorporated in the auxiliary burden.

Bushing potential devices shall be provided with tapped capacitor in the secondary circuit to correct the actual burden, assumed to be at 0.60 power factor lagging, to the rated burden at unity power factor, in 5-volt-ampere steps.

Adjustment Range and Steps

The maximum range over which adjustment shall be required and the maximum steps of adjustment shall be:

Class of Device	Maximum Range of Adjustment		Maximum Tap Steps	
	Ratio (Per Cent)	Phase Angle (Deg)	Ratio (Per Cent)	Phase Angle (Deg)
A	±5	±5	1	1
B	±5	±5	2	2
C	*	30–150	2	5

* Not specified.

Protective Gap and Grounding Switch

A protective gap set at not less than twice the maximum steady-state operating tap voltage shall be provided. A switch shall be provided for grounding the device primary.

Overvoltage Operation

Devices shall be capable of momentary operation with rated burden at circuit overvoltages not exceeding two times normal line-to-neutral voltage without becoming unstable.

Insulation Level

The insulation level of potential devices, and shunt and/or auxiliary capacitors, etc., in the primary circuit, shall be the same as used for instrument transformers of corresponding voltage class. The secondary winding, capacitors, etc., in the secondary circuit shall receive a test of not less than 2,500 volts, in accordance with instrument-transformer practice, proposed ASA Standards for Transformers, *C57*, page 34, table 7.

References

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Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 Supplement to Electrical Engineering—Transactions Section.

A Method for Detecting the Ionization Point on Electrical Apparatus

G. E. QUINN
MEMBER AIEE

When any part of the air path included in the insulating circuit of a piece of electrical equipment is overstressed, ionization occurs. The critical value of voltage is a function of the nature of the remainder of the dielectric circuit, the manner of use, surface conditions, the proximity of grounded conducting bodies, the temperature, and in some cases, the relative humidity. Ionization in air causes the formation of small quantities of ozone and oxides of nitrogen. The presence of ozone leads to accelerated aging of insulating materials, especially organic materials such as varnished cambric and paper. The oxides of nitrogen may combine with water to form nitrous and nitric acids which attack cellulose materials and metals. While increasing temperature tends to decrease the voltage at which ionization occurs or to increase its severity at a given voltage, this effect is somewhat offset by the fact that the acids formed are decomposed at temperatures above 80 degrees centigrade. Under certain conditions increased humidity on the other hand not only causes more severe ionization at a given voltage but increases the severity of the action on the cellulose insulation or metal parts which may be present. Nonleaded cables have been known to fail in a few years when subjected to apparently mild ionization under high-humidity conditions. Ionization produces radio interference either by direct radiation or by conduction along the supply circuit or some paralleling circuit.

The minimum voltage at which ionization occurs on a piece of electrical equipment is of interest to both manufacturer and user. The necessity to arrest this condition and not wait until ionization is visible or audible has long been obvious with the result that a number of methods have been proposed for the determination of the voltage at which ionization occurs.[1–2] The method most commonly used at present is probably the one given in the "Report of the Joint Coordination Committee on Radio Interference of the EEI, NEMA, and RMA". Using this method the "radio noise influence voltage" of the equipment under test is measured and it is therefore essentially a radio-interference test. It is, however, satisfactory as a means of detecting the voltage at which ionization occurs on apparatus which can be tested at locations not subject to stray interference. It is often necessary for this work to be conducted under severe stray field conditions and it is the purpose of this paper to describe a simpler and less expensive method which may be used under such circumstances.

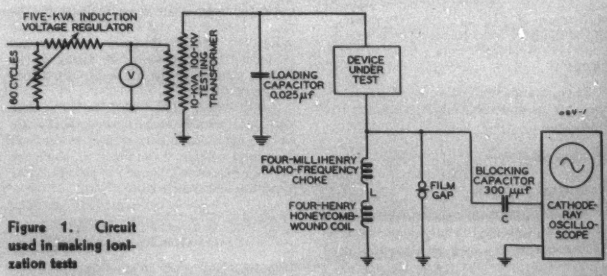

Figure 1. Circuit used in making ionization tests

In the proposed method a cathode-ray oscilloscope is used to detect the pulses, surges, or damped oscillations introduced into the charging current by ionization

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1. For all numbered references, see list at end of paper.

Figure 2. Test set-up for determining ionization point on 5,000- to 5-ampere 15,000-volt current transformer

A circuit used with considerable success is shown in figure 1. A reactor L is inserted in the ground lead of the device under test and the voltage drop across this reactor is applied to the oscilloscope. Some time ago Lloyd and Starr[4] applied the drop across a resistor to an oscilloscope in a study of corona loss. While this method served its purpose it is not adequate for ionization-point determination. If this resistor is replaced by a suitable reactive shunt the usefulness of the method is greatly increased. Referring to figure 1 it will be noted that the reactive shunt is made up of a four-millihenry radio-frequency choke in series with a four-henry honeycomb-wound coil. This combination of impedance is used in order to obtain maximum deflection of the ionization components of current on the oscilloscope. The radio-frequency choke has a distributed capacitance of about one micromicrofarad and produces maximum drop for the high-frequency components of the ionization current while the four-henry coil is effective on the lower-frequency components. A blocking capacitor C is used in series with the oscilloscope in order practically to eliminate the test-frequency current appearing on the screen thus making it more readily possible to detect the first evidences of ionization. In addition, the oscilloscope may be operated with constant amplification as the voltage on the apparatus under test is increased.

A loading capacitor is connected in parallel with the device under test to provide a low-impedance path for ionization currents produced. By disconnecting this capacitor a simple means is provided for checking whether the oscilloscope is indicating ionization produced by the device under test or ionization inherent in the test setup. If the indication on the oscilloscope is due to ionization currents produced by the device under test, the indications will decrease. If it is due to a faulty test circuit the indications will increase because the short-circuiting effect of the capacitors will no longer be present.

The oscilloscope is a standard model with self-contained amplifiers and the sensitivity is usually set for 0.005 inch per millivolt deflection of the beam. It has been found that further increase in sensitivity increases the magnitude of the indication only, without appreciably decreasing the voltage at which oscillatory discharges are first detected.

In setting up this equipment, care should be taken to have all high-voltage connections free from sharp corners and edges in order to prevent ionization from these sources. Ground connections should be solidly made and capable of carrying the full short-circuit current of the testing set. In addition, a film gap of low capacitance should be connected as shown in figure 1 for further protection of the operator. Figure 2 is a photograph of a typical test setup, and shows a 15,000-volt 5,000-ampere current transformer under test. A shielded lead is shown connecting the oscilloscope to the reactive shunt. The two coils which make up the reactive shunt L will be noted on the table in front of the current transformer.

In using this setup the voltage applied to the device under test should be increased in about 200-volt increments and the oscilloscope observed at each value for indications of ionization. The sweep circuit of the oscilloscope should be adjusted for the test-circuit frequency or some submultiple thereof in order that the trace of the screen be stationary. The oscillatory discharges which accompany ionization appear superimposed on the charging current.

The definiteness with which the ionization point can be determined using this circuit can be seen in figure 3. The device under test in this case was a 3,000-volt lightning arrester. The marked difference between the oscilloscope traces obtained at 200-volt increments leaves no doubt as to the point of inception of ionization. These traces were obtained using a sensitivity of 0.005 inch per millivolt. Though the ionization point is not always as sharply defined in all pieces of equipment, it has been found that if the sensitivity is increased sufficiently oscilloscope traces similar to those shown on this figure may be obtained on any piece of equipment. The voltage at which ionization is detected at greatly increased sensitivity has been found to be not more than 200 volts below the value noted by a trained observer when the oscilloscope is set for normal sensitivity.

Figure 4 is an oscilloscope trace of ionization encountered at 6,000 volts on a 5,000-to-5-ampere 15,000-volt current transformer. The test circuit and sensitivity were the same as those used in obtaining the traces shown in figure 3.

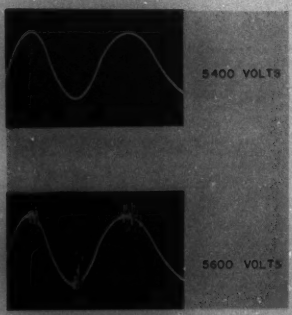

Figure 3. Oscilloscope traces showing the point of inception of ionization in a lightning arrester

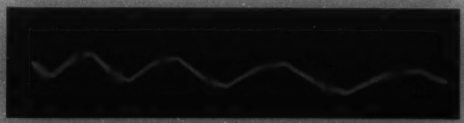

Figure 4. Oscilloscope trace showing ionization at 6,000 volts in a new 5,000- to 5-ampere 15,000-volt station-type current transformer

Table I. Results of Ionization Tests Using "Radio Noise Influence Voltage" Circuit and Cathode-Ray-Oscilloscope Method

Device Number	Type of Equipment	Minimum Voltage at Which Disturbance Was Noted			
		Increasing Voltage		Decreasing Voltage	
		Oscilloscope	Noise Meter	Oscilloscope	Noise Meter
1	Lightning arrester (repaired)	600	600	550	550
		500	500	500	500
		500	500	500	500
		Avg. 550	550	500	500
2	Lightning arrester (repaired)	2,000	2,000	1,750	1,750
		1,750	1,750	1,750	2,000
		2,200	2,200	1,750	1,750
		Avg. 2,000	2,000	1,750	1,850
3	Lightning arrester (repaired)	500	500	Less than 500	2,500
		600	3,000	800	3,000
		1,000	3,000	600	2,600
		Avg. 700	2,200	Less than 700	2,700
4	Current transformer (repaired)	1,300	1,300	800	950
		1,500	1,500	1,700	1,700
		1,800	1,800	2,650	2,650
		Avg. 1,550	1,550	1,700	1,750
5	Current transformer (new)	9,500	9,500	6,100	6,100
		9,000	9,000	4,500	4,500
		9,000	9,000	5,000	4,500
		Avg. 9,200	9,200	5,200	5,050
6	Current transformer (new)	4,700	4,700	4,800	4,800
		5,300	5,300	5,100	5,100
		4,900	4,900	4,700	4,700
		Avg. 5,000	5,000	4,900	4,900

Visual corona on this transformer was not detected until the voltage had been increased to 16,500 volts. Although this transformer is of recent manufacture, it can be seen from the figure that there is unmistakable evidence of ionization at a voltage considerably below the intended operating voltage to ground. This may be taken as evidence of a defect in this transformer since transformers of identical design and similar manufacturing processes, which were tested at the same time, showed no evidence of ionization below operating voltage to ground.

A series of tests comparing the oscilloscope method and the "radio noise influence voltage" method were made recently under normal laboratory conditions. Throughout these tests, intermittent stray disturbances were picked up by the radio-noise meter. At times these became so severe that it was found necessary to delay the tests until the stray interference decreased sufficiently to permit a satisfactory determination of the amount of interference generated by the device under test. In the case of the cathode-ray oscilloscope the external disturbances were identified by the nature of their appearance on the screen and therefore did not materially interfere with the progress of the test. External disturbances appeared on the oscilloscope as random oscillations at no definite point, whereas the high-frequency discharges from the device under test were always repeated at definite points on the screen since the frequency of the sweep circuit was set at a submultiple of the test frequency.

The results of the tests given in table I are reported as the minimum voltage at which the frequency discharges and radio interference were detected for both ascending and descending voltage on each device tested. The results of the test show that with the exception of one measurement obtained on current transformer designated device number 5 the oscilloscope indicated high-frequency discharges at or below the minimum voltage at which interference was noted on the radio-noise meter.

It will be noted that on the lightning arrester designated device number 3 high-frequency discharges were observed on the cathode-ray oscilloscope at voltages considerably below those at which interference was noted by the radio-noise meter. In order to study this further arbitrary values of the amplitude of the discharges were obtained. These extended from 0.05 inch at 200 volts to 3.70 inches at 4,250 volts. The radio-noise meter first detected interference at approximately 3,000 volts. The insensitivity of the radio-noise meter at the low voltages may have been due to a lack of interference at the frequency to which it was tuned.

In all of these tests the radio set was tuned to a frequency of approximately 1,000 kilocycles. It was found on an additional test that the noise measured by the radio-noise meter increased appreciably as the tuning frequency of the receiver was increased from 1,000 to 1,400 kilocycles with constant voltage applied to the device under test. This is contradictory to claims made for this method and indicates that further work should be done along this line.

The cathode-ray-oscilloscope method of detecting the ionization point of equipment has been used on many other types of electrical equipment including sections of bus, ground and test switches, disconnect switches, cables, porcelain pin-type insulators, and distribution transformers. All this work has served to illustrate the importance of a standard method for determining the ionization point of equipment and the desirability of treating this as the basic problem rather than using the secondary approach of radio noise.

While it is admitted that further work needs to be done in connection with the determination of ionization voltages, it would appear that the following conclusions may be drawn:

1. A cathode-ray oscilloscope used in connection with an appropriate air-core reactor will detect high-frequency discharges at or below the minimum voltage at which radio interference may be noted by the "radio noise influence voltage" method.

2. Since ionization when continued over a long period of time might have a deteriorating effect on the apparatus under test, it is important to know the minimum voltage at which it occurs.

3. The oscilloscope method is simple and satisfactory and is not affected by stray fields.

4. The oscilloscope method is dependable as a means of detecting disturbances over a very wide band of frequencies.

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2. Bulletin No. 259 and 260, University of Illinois Experiment Station.

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4. Corona Loss Measurement by Means of the Cathode-Ray Oscilloscope, **Lloyd and Starr.** AIEE Transactions, 1927, page 997.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 Supplement to Electrical Engineering—Transactions Section.

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Industrial Notes

Sales Appointments.—Harry L. Williamson, formerly assistant manager of cable sales for the General Electric Co., has been appointed manager of sales promotion for the Locke Insulator Corp., Baltimore, Md., a G-E affiliate. Mr. Williamson had been associated directly with General Electric since 1928. His affiliation with the cable section began in 1930 and he was made assistant manager of cable sales in 1936. . . . . The John A. Roebling's Sons Co., Trenton, N. J., has appointed Roger H. Clapp, formerly Philadelphia branch manager, as assistant general manager of sales. Mr. Clapp came to the Roebling company in 1936 and was manager of the Philadelphia branch until his present appointment.

Increased Westinghouse Production.—To meet transformer requirements under the Government's national defense program, production has been increased at the Westinghouse works, Sharon, Pa., world's largest plant devoted exclusively to transformer manufacture. Being built in the plant at present are 500 distribution and instrument transformers for Navy shipbuilding, also, three electric furnace transformers, among the largest ever built. One, rated at 12,000 kva, will supply current to an electric furnace in a steel mill which is turning out alloys for airplane parts. The last of seven 50-ton transformers for Bonneville Dam in Washington is nearing completion. These transformers are at 25,000 kva each.

Recent G-E Sales.—Included among recent General Electric orders is an 80,000-kw turbine-generator for the 465,000-kw Charles R. Huntley steam station of Buffalo Niagara Electric Corp., near Tonawanda, N. Y., as part of an expansion for this station which will involve a total expenditure of $6,000,000. Electric equipment for new hydroelectric power stations to be located at Nantahala and Glenville, N. C., consists of two G-E 27,000-kva, 150,000-volt, 3-phase transformers, and a 54,000-kva vertical waterwheel driven generator, together with a motor-generator exciter set for the Nantahala Power & Light Co. Four 9,000-kva, 150,000-volt, single-phase transformers are to be installed at the Glenville station.

Trade Literature

Recording Demand Meters.—Bulletin B-2234, 16 pp. Describes a complete line of recording kw-demand meters for all classes of services in common use. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Distribution Systems.—Bulletin 61, 16 pp. Describes feeder "busduct," "plugin busduct," and "plugin" devices and accessories used in industrial distribution systems. Prices are included. Frank Adam Electric Co., 3650 Windsor Place, St. Louis, Mo.

Oil Circuit Breakers.—Bulletin B-6003, 4 pp. Describes very large units available in standard ampere and interrupting capacity ratings from 15 kv to 69 kv. Bulletin B-6093, 4 pp., covers small units in standard ratings from 15 kv to 23 kv. Distinctive features include quick quench ruptors, high speed solenoid operator and accessible control cabinet. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Portable Substations.—Bulletin GEA-3413, 4 pp. Describes fully equipped, trailer mounted portable substations. They are applicable for emergency use, standby service for handling seasonal and other types of temporary overloads, to continue service during inspection or repair work, or to supply power for construction jobs and numerous other temporary power needs. General Electric Co., Schenectady, N. Y.

Wires and Cables.—Catalog 102, 36 pp. "Rubber Covered Wires and Cables—Service Entrance Cables". Describes and illustrates process of manufacture; covers standard rubber insulated building wires, service entrance cables; contains complete data with tables, etc., on small diameter (thin-wall) building wire, including methods of selecting wire sizes for new or rewiring installations. Examples of the manner of using these tables to determine proper conductor selection for various requirements are included. John A. Roebling's Sons Co., Trenton, N. J.

Power Plugs and Sockets.—Bulletin 500, 8 pp. Describes and illustrates a new series of power plugs and sockets designed for 5,000 volts and 25 amperes, and made in 2, 4, 6, 8, 10 and 12 contacts. All sizes are polarized so that it is impossible to make incorrect connections, even when using several sizes on a single installation. The cap is arranged so that a standard cable clamp can be used; connections are easily and quickly made, and cap body can be removed for inspection without disturbing wiring. Howard B. Jones, 2300 Wabansia Ave., Chicago, Ill.

Voltage Regulators.—Bulletin 51-2, 20 pp. Includes a comprehensive technical discussion, illustrated with 26 wiring diagrams showing how small, type TH Transtat voltage regulators may be used in multi-unit gangs and with auxiliary transformer equipment for controlling input voltage to loads which are outside the usual limits of kva, voltage, current or phase of the regulator element; also, complete descriptive data on type TH Transtat voltage regulators and type LC Transtat line voltage compensators. The text is accompanied by illustrations, outline drawings and a tabulation of standard ratings, with prices, weights and dimensions. Type TH Transtats are offered in larger sizes than were previously manufactured. These units are designed to provide an adjustable output voltage with regulation over a range of 0 to 113 per cent of input in small increments and without circuit interruption. Type LC Transtats are designed to permit manual correction of variations in line voltage, being a new design of regulator announced for the first time in this bulletin. American Transformer Co., 176 Emmet St., Newark, N. J.

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"IRVINGTON" BLACK SEAMLESS BIAS VARNISHED CAMBRIC AND TAPE are similar in general characteristics to Black Straight Cut Cambric but are ideal for covering curved and irregular surfaces, maintaining good dielectric strength after stretching.

"IRVINGTON" YELLOW SEAMLESS BIAS CAMBRIC AND TAPE have properties similar to Yellow Straight Cut Cambric and are recommended for use on curved and irregular surfaces, maintaining good dielectric strength after stretching.

"IRVINGTON" VARNISHED CAMBRIC CABLE-CLOTH is manufactured to meet a variety of differing specifications.

Specify "IRVINGTON" VARNISHED CAMBRIC and TAPE

"IRVINGTON," pioneer in the commercial development of varnished insulations, was the first to produce seamless bias varnished cambric and tape, the first to perfect the manufacture of black varnished cambric.

Constant research and development have produced in "IRVINGTON" Varnished Cambric and Tape a balance of mechanical and electrical properties that is unsurpassed for commercial insulation applications. These insulations generously comply with appropriate N.E.M.A. and A.S.T.M. specifications. Samples for your own test will be forwarded upon request.

"IRVINGTON" varnished insulations due to their pliability and smoothness of finish are adapted to every requirement of hand or machine application and "IRVINGTON" production facilities have been expanded to a point that insures continuity of supply.

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IRVINGTON VARNISH & INSULATOR CO.

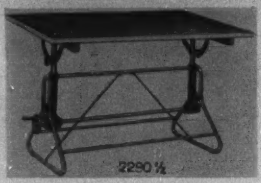
IRVINGTON, NEW JERSEY, U. S. A.

PLANT AT GEORGETOWN, ONT., NEAR HAMILTON, CANADA

IRVINGTON INSULATION

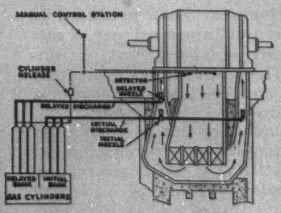
New Products

Drafting Tables.—Two new drafting tables developed by The Frederick Post Co., P. O. Box 803, Chicago, Ill., feature appearance as well as utility. They are constructed of satin chrome tubular steel, with table tops



of selected pine $1^1/_8$ inches thick. The type illustrated, "Primo Metapost", is quickly adjusted by turning a handwheel which will raise the working surface from 35 to 43 inches. The top of the table may be tilted from front to back at an angle of 60° by a manual adjustment of two hand clamps. Another model, the "Metapost" has the same adjustment features as the "Primo Metapost," except that instead of wheel control, two easily reached thumb screws permit the table top to be manually raised or lowered. These tables are available in 11 table top sizes ranging from 31 by 42 inches to 48 by 96 inches. Reference shelves, which can be furnished, and provide ample space for tracings, materials, etc., may be easily attached to either model.

Generator Fire Protection.—A new development in the protection of rotating electrical machines from fire, introduced by Walter Kidde & Co., 140 Cedar St., New York City, manufacturers of carbon dioxide extinguishing equipment, consists of the use of special shielded nozzles for the discharge of carbon dioxide into the ventilating



ducts of generators in event of fire. As shown in the illustration, the shielded nozzles are affixed to both the initial discharge and the delayed discharge pipes which carry the carbon dioxide from the storage cylinders to the ducts, and the refinement is said to eliminate objectionable high jet velocity and turbulence. Also, the new nozzles aid in achieving a more rapid and uniform distribution of the fire-killing gas throughout the machine.

Cable Terminal.—The "streamlined" cable terminal, type SNA-H, developed by the Burndy Engineering Co., Inc., 459 E. 133rd St., New York City, is especially designed to facilitate easy taping of the connector and helps insure a moisture-proof seal to the insulation. A recess at the cable entrance

permits the end of the cable insulation to be inserted into the connector and thereby shrouds and protects the cut end of the insulation. The illustration shows the terminal with the cap clamped on the conductor by means of hollow head cap screws. This type of connector, available in all cable sizes up to 3000 mcm, is also made with hexagon head cap screws set in recesses in the cap in such a manner that they can be tightened with an ordinary socket wrench.

Whiteprint Machine.—A new, medium-priced, model F whiteprint machine, introduced by the Ozalid Products Div., General Aniline & Film Corp., Johnson City, N. Y., consists of a printer and dry-developing unit built into a single, compact machine, combining all the facilities necessary to turn out

finished dry-developed Ozalid whiteprints. Equipped with a new type high pressure mercury vapor lamp, which uses 40 watts per inch and has an active length of 46 inches, the model F will print Ozalid sensitized materials at speeds up to 56 inches per minute. The lamp is guaranteed for 1,000 hours, but tests indicate a life of from 1,500 to 2,500 hours. Lamps which burn out can be reworked for considerably less than the purchase price of a new lamp. The efficiency of the new model F light source cuts current consumption more than 50 per cent of that required by other machines of similar capacity. Even cooling of the lamp, so necessary for uniform light distribution, is provided by a two-stage blower and a specially designed air duct. Maximum lamp efficiency is assured by a reactive type transformer equipped with condensers providing power factor correction to 87.5 per cent. A counter automatically registers the number of hours the machine operates.

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RATES: Fifty cents per line; minimum charge based on use of five lines; maximum space not to exceed thirty lines. Copy is due the 15th of the month preceding publication date.

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WANTED: Electrical engineer, experienced in the design of distribution and power transformers, particularly the latter. Give qualifications in full. Address Box 201, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

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For transmitter or receiver designing on radio or special apparatus. Openings for U.S. citizens. Offering excellent opportunities to men with experience in the design of radio or special electrical apparatus. In reply state experiences that will qualify, age, present salary, etc. Address Q-53, P.O. Box 3443, Philadelphia, Penna.

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Needed by radio manufacturer. Splendid opportunities for men with radio or equivalent, experience such as required for designing the mechanical features of speakers, receivers, transmitters or special apparatus. Steady work, large manufacturer located in eastern part of United States. Write for interview giving full qualifications. Address P-52, P.O. Box 3571, Philadelphia, Penna.

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Design division of large industrial company desires graduate electrical engineer, preferably one who has completed advanced studies in physics, mathematics, and advanced electrical theory. Should be 35 to 40 years of age, have 5 to 10 years experience in power plant, transmission or advanced development and application work. Particular type of experience is not considered so important as thorough grounding in fundamentals and ability to grasp both the theoretical and practical problems involved in the design, construction and operation of large industrial plants producing and using electric power on a large scale. Give full experience, college education, present salary, salary desired, age, and enclose recent snapshot of yourself. Will keep confidential. Address Box 203, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

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Today with *production for defense* straining the facilities of an ever widening group of plants, the need for unquestioned dependability in instrumentation grows more acute. From the generators, through the laboratories to final assembly and inspection lines, *truthful indications* are essential to prevent work interruptions and waste . . . assure peak efficiency at every step. *It's a period which challenges the dependability of instruments . . .* and, as in all like periods, the demand for WESTONS daily grows apace. For WESTONS fully meet this challenge with their proved combination of *unquestioned accuracy* and *long-time dependability*. It's the same combination which make WESTONS "first choice" in normal times . . . and it becomes an ever more valid reason for WESTON preference today. Weston Electrical Instrument Corporation, 618 Frelinghuysen Avenue, Newark, New Jersey.

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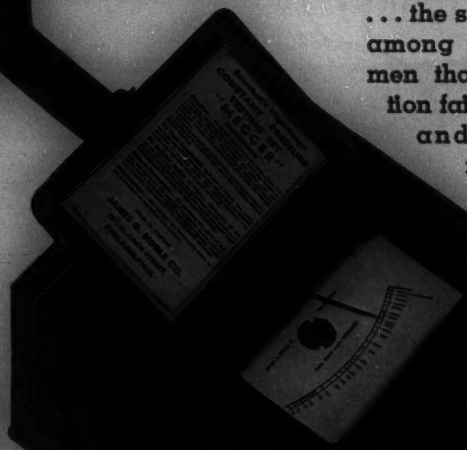
. . . the symbol of a procedure among practical electrical men that anticipates insulation failure, forestalls trouble and saves lives and money.



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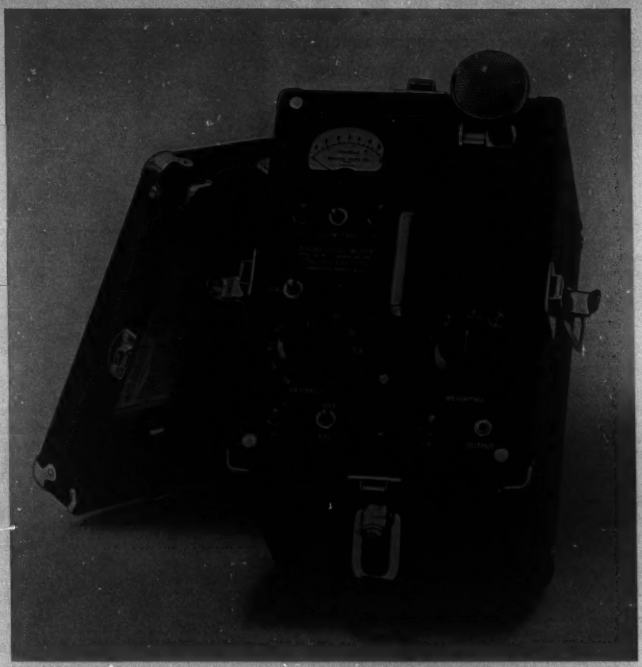

With this Accurate, Highly Stable Meter

WITH THE IMPROVED General Radio Sound-Level Meter the intensity of sound can now be measured conveniently, quickly and accurately by anyone. This instrument is widely used throughout industry for all types of noise measurements and studies. It is completely self-contained and portable and will measure the intensity of sound from a whisper to a steam whistle.

FEATURES:

1 **EXCEPTIONALLY WIDE RANGE**—24 to 140 db

2 **SIMPLIFIED CONTROLS**—complete db range covered by a single control knob

3 **IMPROVED MICROPHONE**—special type of great sensitivity, highly rugged, unaffected by ordinary changes in temperature and humidity

4 **PLUG-IN MICROPHONE**—normally used directly on folding socket on instrument but can be detached and used with cable and tripod if desired

5 **SLOW-FAST METER**—two speeds—control switch selects either; "fast" position, meter movement corresponds to A. S. A. standards; "slow" position, meter heavily damped to measure average level fluctuations.

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8 **NO COILS**—instrument contains no coils or inductances and accordingly reads accurately in the presence of any ordinary magnetic field

TYPE 759-B SOUND-LEVEL METER.....$195.00

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GENERAL RADIO COMPANY, Cambridge, Massachusetts

THE Standards of the American Institute of Electrical Engineers now comprise forty-eight sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.

The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members (except on Nos. C57.1, 2 and 3). Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available, with durable, stiff covers, resembling leather, lettered in gold. Price, $1.75 net.

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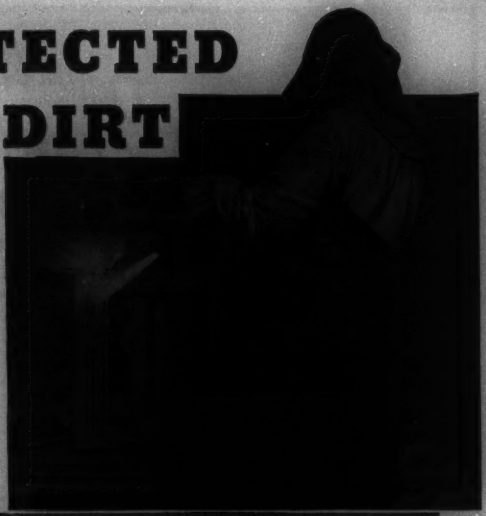
Seven such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request. These sections are as follows:

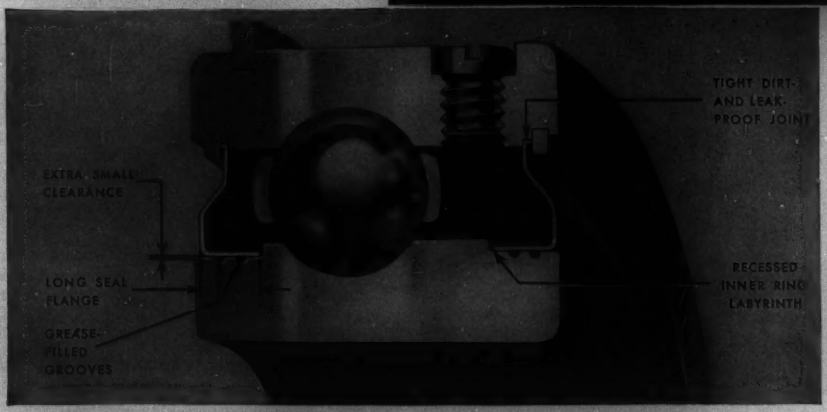
No. 6 Mercury Arc Rectifiers.	501 Test Code for D-C Machines.
24 Protector Tubes	40 Electrical Recording Instruments.
25 Fuses Above 600 Volts.	— Test Code for Synchronous Machines.
17g1A Letter Symbols for Electric and Magnetic Quantities.	

American Institute of Electrical Engineers 33 West 39th Street New York

FULLY PROTECTED AGAINST DIRT



Made to Standard Double-Row Widths
WITH 100% GREATER GREASE CAPACITY



A clean, well-lubricated bearing is practically wearless. Dirt, however, will relentlessly destroy it. KEEP DIRT OUT AND KEEP THE GREASE IN, and you are protected against noise, rejections, and premature wear.

In the illustration herewith, note the five distinctive features that exclude dirt from the "CARTRIDGE" BALL BEARING. That minute clearance between the long seal flange and recessed inner ring is ALWAYS filled with grease. The grease grooves in the inner ring are so many added "dams" against the entrance of dirt.

Thus, without any additional closures, the integral "CARTRIDGE" seals KEEP THE DIRT OUT AND THE GREASE IN—regardless of the position of motor or unit. In assembling or disassembling in the shop, the "CARTRIDGE" BALL BEARING STAYS CLEAN because its internal parts are never exposed.

Adopt the "CARTRIDGE" BALL BEARING as insurance against dirt and grease contamination, and against neglected lubrication. It eliminates numerous supplementary closure parts and machining operations and variables, and speeds up production; and it has convenient regreasing and inspection features.

Write for the Catalog. Let our engineers work with yours.

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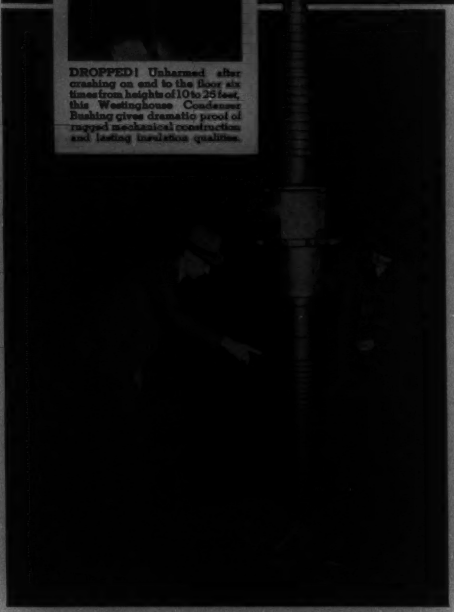
DROPPED! Unharmed after crashing on end to the floor six times from heights of 10 to 25 feet, this Westinghouse Condenser Bushing gives dramatic proof of rugged mechanical construction and lasting insulation qualities.

Damage TO INSULATION
Slippage BETWEEN FOIL AND PAPER
Leakage DEVELOPED
} None!



INTACT! Examination after six succeeding drops of 10 to 25 feet disclosed no damage. Standard commercial high potential and power factor insulation tests showed bushing electrically unaffected—air pressure test proved condenser intact and free from leakage.

EXTREME TESTS PROVE STRENGTH OF MODERN WESTINGHOUSE CONDENSER BUSHINGS

The most compact in size, paper-wound condenser type bushings are the strongest as well. Constant improvement in materials and processes, together with drastic tests have produced in today's Westinghouse Condenser Bushing a unit which defies moisture, extremes of temperature, and mechanical and electrical stresses.

Use of electrolytic copper foil now gives even greater adhesion between layers composing the condenser unit. The improved insulating compound between condenser and porcelain is non-hardening and is heavier than water. At lowest operating temperatures, perfect cohesion prevents voids, and adhesion to condenser and porcelain prevents moisture from reaching the condenser. New standardized cap for all bushings improves top seal, makes testing easier.

Investigate what these improvements mean in new low costs for bushing maintenance and replacement. See your Westinghouse representative or write Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., Dept. 7-N.

OVERVOLTAGE . . . UNDER WATER . . . 2½ YEARS! One of several Westinghouse Condenser Bushings tested continuously for more than 2½ years at 50% overvoltage with water on top of the plastic filler throughout the entire period. Absolutely no emulsification or moisture absorption has occurred. Power factor tests show no effect on electrical characteristics of the condenser insulation.

Westinghouse
CONDENSER BUSHINGS

ALCOA

The armor rods being installed here, for example, are classed as "right" by the men who know. Power line conductors, *no matter what they're made of*, have a tendency to vibrate under certain conditions. Armor rods offer protection against fatigue, flash-overs, and wear at points of support.

Armor rods are but one of the devices recommended by Alcoa engineers for increasing a line's dependability. A.C.S.R. engineering standards include complete wire stringing data and a perfected system of vibration control. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh, Pennsylvania.

A·C·S·R

Aluminum Cable Steel Reinforced

FOR MODERN TIMES AND POWER TRANSMISSION

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1500 KW, 250 VOLT SYNCHRONOUS MOTOR GENERATOR SETS

for immediate shipment

These are Westinghouse units—compound wound, .8 P.F., 514 r.p.m., 3 phase, 60 cycle.

Unlike ordinary used equipment, these motor-generator sets are in first class electrical and mechanical condition. The cost of each is only a fraction of similar new equipment.

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For capacities above 200 VA. Housing type.

From 20-200 VA. Primary cord set, and output receptacle.

A new unit for applications up to 16 VA. Equipped with leads or terminals.

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Fully automatic, instantaneous in operation. SOLA CONSTANT VOLTAGE TRANSFORMERS have no moving parts and require no maintenance. They are self-protecting and cannot be damaged by short circuit. AND—they will maintain their output voltage to within a fraction of a percent of the specified value, even though the line voltage varies as much as thirty percent.

You can build a SOLA CONSTANT VOLTAGE TRANSFORMER into your product and stop worrying about your customer's line voltage.

You can build a SOLA CONSTANT VOLTAGE TRANSFORMER into your production line or your laboratory and know that every test will be made under the same line conditions.

You'll find these SOLA CONSTANT VOLTAGE TRANSFORMERS surprisingly compact—and economical, too. To augment or replace non-regulating types, standard designs are available, or units can be built to your special specification.

Write for catalog ACV-22

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Perfect **INSULATING COMPOUNDS**

for a wide range of temperature

In the Northern States, on the Gulf Coast, and both east and west—Minerallac Insulating Compounds are specified . . . proving that these materials do "stand up" no matter what change in temperature may arise.

• WRITE FOR BULLETIN 186 •

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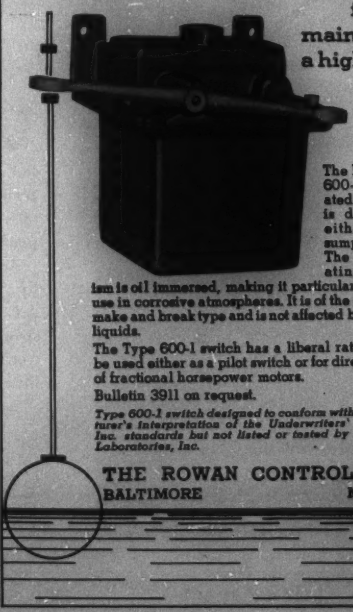
OIL-IMMERSED FLOAT SWITCH for maintaining a high or low liquid level



The Rowan Type 600-1 rod operated Float Switch is designed for either tank or sump operation. The entire operating mechanism is oil immersed, making it particularly suited for use in corrosive atmospheres. It is of the quick acting make and break type and is not affected by oscillating liquids.

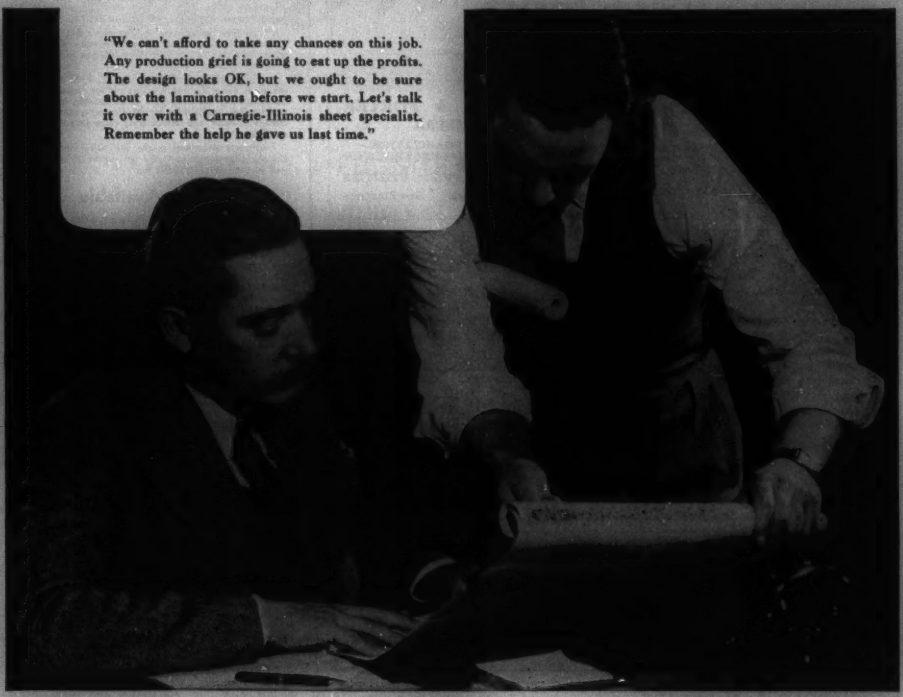
The Type 600-1 switch has a liberal rating and can be used either as a pilot switch or for direct operation of fractional horsepower motors.

Bulletin 3911 on request.

Type 600-1 switch designed to conform with the manufacturer's interpretation of the Underwriters' Laboratories, Inc. standards but not listed or tested by Underwriters Laboratories, Inc.

THE ROWAN CONTROLLER CO.
BALTIMORE MARYLAND

"Let's make sure we are using the *Right Steel!*"


"We can't afford to take any chances on this job. Any production grief is going to eat up the profits. The design looks OK, but we ought to be sure about the laminations before we start. Let's talk it over with a Carnegie-Illinois sheet specialist. Remember the help he gave us last time."

THAT'S typical of plant managers who have learned to take advantage of the services of the Carnegie-Illinois electrical sheet specialists. These men are trained to know which sheet will give the best performance, the right electrical properties—to specify the proper grade and most economical sheet size to use. They are familiar with such problems as annealing and core plating. On the job day and night, they will stay with you until your trouble is licked. And because of their broad experience with the production of electrical equipment they are often able to help you in other ways.

Why not call in the man from Carnegie-Illinois? Problems arising from the use of electrical sheets should be his worry, not yours. Let him work your problem out right in your own plant. It won't cost a cent, and may save you a lot of money and production grief.

Make sure you have specified the right steel for *your* latest design.

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For Motors, Generators and Transformers

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Engineering Societies Personnel Service, Inc.

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the four offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

TRANSF ENGR, des, devpmt, sales or research, B.S.E.E., 1932; 29; can offer neatness, orderliness, ability and new ideas. E-736.

ELEC-MECH ENGR. Seven yrs large elec util cos gaining both const and oprtg exper, followed by 7 yrs leading consulting engg firms, thoroughly conversant with regulatory commission work. Desires pos, preferably at New York. E-737.

B.S.E.E., 1934; 29, married; exper meter dept, overhead distr; now employed as Managing Engr small util. Desires pos as distr engr or elec sales promotion engr. E-738.

B.S.E.E., Univ of Pa, 1934; Associate AIEE; 28, married; 5 yrs util exper, viz underground network, overhead transm and distr, step voltage regulators. Present rating, Engr, Distr. E-739.

B.S.E.E., 1938; Associate AIEE; 4 yrs com lab tech. 1 yr Field Intensity Research. Exper marine and broadcast radio oprtg. Instructor radio oprtg. Desires pos com. Available immed. E-740.

M.S.E.E., advanced work 2 excellent schs; N. Y. license; married; 10 yrs broad and intensive teaching, organizing and indus exper in pwr and com; desires opportunity in teaching, organizing, tech investigation. E-741.

SALES ENGR, 48, married; 25 yrs sales exper indus and constr elec. eqpt. Specialist ltg and pwr sales. Ability train, direct, build up sales. Seeking pos where develop. E-742.

ELEC ENGR, Fellow AIEE, professional license, varied util, indus exper, U. S. and abroad. Past 15 yrs chief engr, gen supt, util in Mississippi Valley; exper in continuing property records. E-743.

B.S.E.E.; 3 yrs Law, night, eligible Bar many states; 28, married; 6 yrs pub util com exper, rates, contracts, valuations, financial, depreciation and cost studies, oprtg problems, regulatory procedure. E-744.

ELEC ENGR, 18 yrs exper des, mfg, sales rotating elec machy. Chief engr several cos. Can handle engg mfg, application and sales. Seeks exec pos in elec or mech industry. E-745.

RECENT GRAD, elec and mech engr; 28, single, ambitious. Desires opportunity for exper leading to responsible engg pos. Interested in sales and production. E-746.

S.M., M.I.T., 1939; B.S.E.E., Univ of Mich, 1936; 24, married; 2 yrs testg engr high voltage lab; 6 mos research, electronic prod. Desires pos research or des engr in high voltage engg, electronics, com. Available immed. E-747.

ELEC GRAD, Pratt Inst, 1934, with some exper in air conditioning eqpt, install and maintenance. Desires pos in same, preferably in East. Available immed. E-748.

B.E.E.; 30, married; employed in meter dept, util co; 5 yrs exper util, steel mill, draftg office; util co or mfg pos desired; midwest preferred; Professional Elec Engr, Ohio. E-749.

INDUS ENGR, 42, married; routing, planning, time study, wage incentive, estimating, mfg, estimating costs. Capable exec, elec and mech. Now employed. E-750.

B.S.E.E., Col City of New York, recent grad; single. Desires pos with mfr of elec or mech prod. Location immaterial, salary secondary. Available immed. E-751.

M.S.E.E., Univ of Minn, 1938; 33, married; 18 mos exper pub util; asst to gen mgr; teaching exper; surveying exper; desires pos with engg future; now employed. E-752-261-Chicago.

ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

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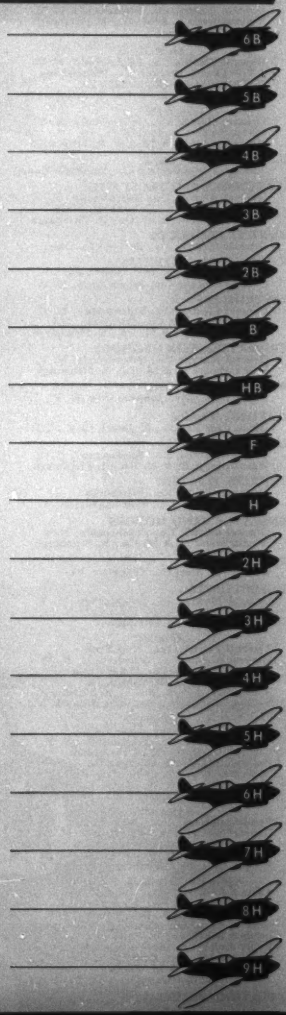

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Crescent Ins. Wire & Cable Co., Trenton, N.J.
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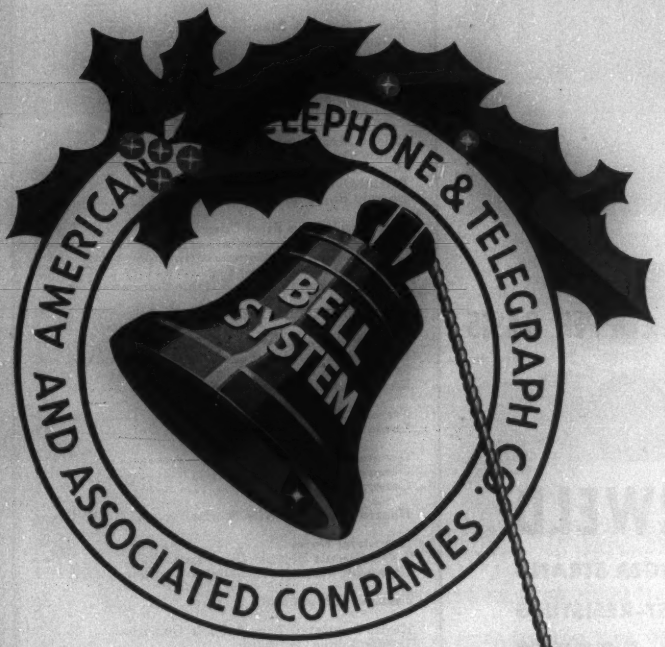

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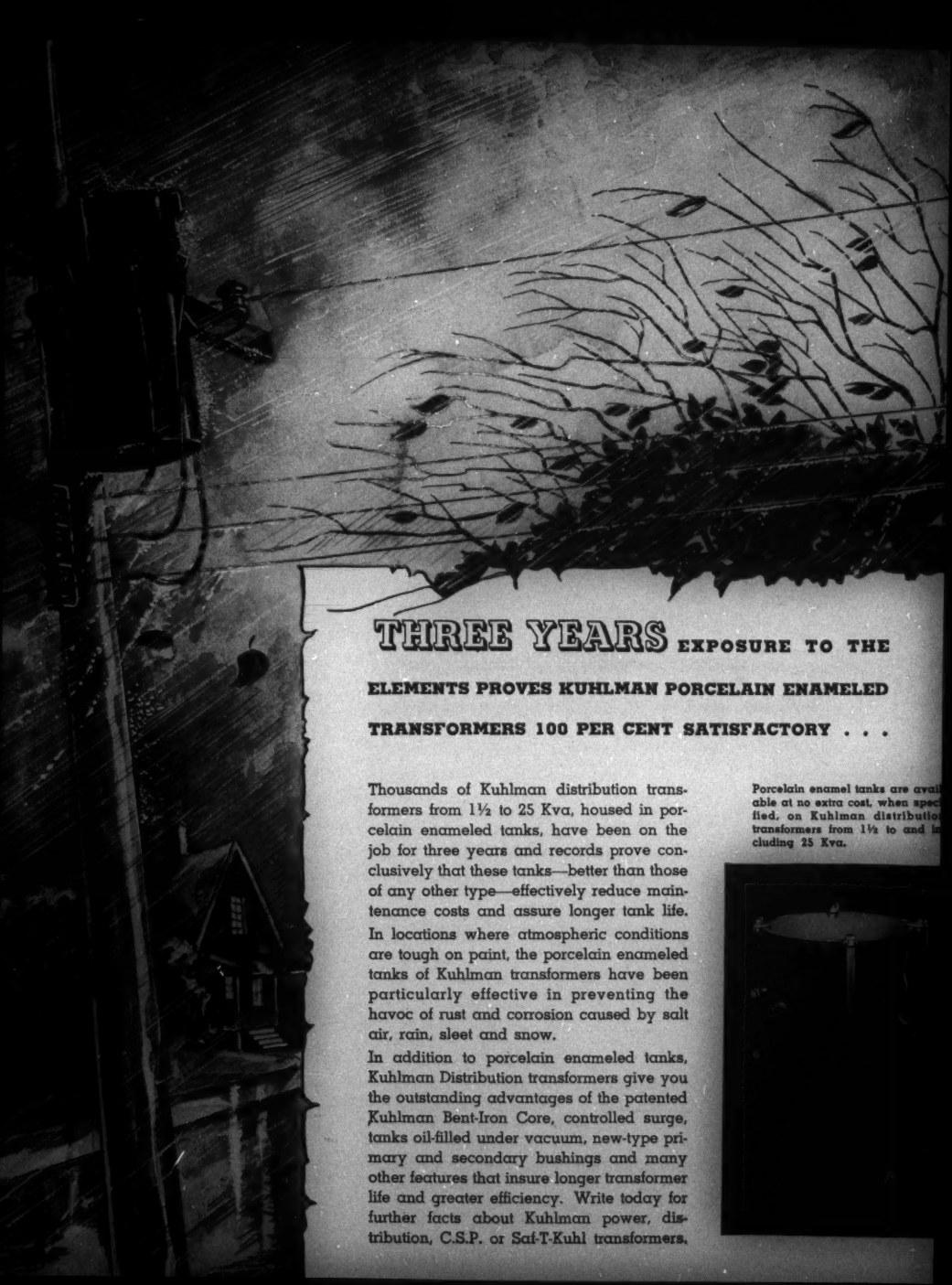

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